Final

Garfield Groundwater Contamination Superfund Site Feasibility Study City of Garfield, Bergen County, New Jersey

Prepared for

U.S. Army Corps of Engineers, Kansas City District and U.S. Environmental Protection Agency, Region 2

Hazardous, Toxic, and Radioactive Waste Contract Number W912DQ-11-D-3005

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Executive Summary

This draft feasibility study (FS) report was prepared for the U.S. Army Corps of Engineers (USACE), Kansas City District, and the U.S. Environmental Protection Agency (USEPA) Region 2 by CH2M HILL (CH2M) to present the results of the feasibility analysis of remedial alternatives for the Garfield Groundwater Contamination Superfund Site in the city of Garfield, Bergen County, New Jersey (site). This FS report has been prepared under USACE, Kansas City District Hazardous, Toxic, and Radioactive Waste Contract Number W912DQ-11-D-3005, Task Order 0003.

On September 16, 2011, USEPA placed the site (USEPA ID NJN0000206317) on its National Priorities List (NPL) of hazardous waste sites requiring further evaluation. Accordingly, USEPA Region 2 performed a remedial investigation (RI) and FS of the site according to the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, or “Superfund”), as amended. The RI was completed between 2011 and 2013, and the results are presented in a Remedial Investigation Report (CH2M 2014a), and the FS was initiated. The results of this FS will be used to develop a proposed plan for remedial action and a Record of Decision for the site.

Feasibility Study Objectives and Scope of Work

This FS develops and evaluates remedial alternatives for hexavalent chromium [Cr(VI)]-impacted source area soils and the associated Cr(VI) plumes in the overburden and bedrock aquifers that will reduce or eliminate unacceptable risks to human health and the environment from exposure to contaminated groundwater. The FS was prepared following USEPA’s *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA 1988a).

Electroplating operations were conducted at the former E.C. Electroplating (ECE) property from the 1930s until 2009. In December 1983, a partially buried vertical storage tank at the property failed, releasing an estimated 3,640 gallons of chromic acid directly into the shallow overburden aquifer and deeper bedrock aquifer. In May 1996, an additional spill was reported at the ECE facility in which approximately 250 gallons of process wastewater flowed from the building onto Sherman Place. Mining Visualization System software results suggest that the current mass of Cr(VI) in the groundwater plume may be up to four times the amount reportedly released during the 1983 and 1996 spills, indicating that unreported spills or leaks may have occurred historically at the former ECE facility (CH2M 2014a).

Chromic acid that entered groundwater has infiltrated into a number of downgradient commercial and residential building basements (USEPA 2012a). New Jersey Department of Environmental Protection (NJDEP) and USEPA have been investigating and remediating impacted basements where elevated levels of Cr(VI) were observed since 1993. In September 2011, the site was officially listed on the NPL, and USEPA completed an RI between 2011 and 2013.

Following completion of RI activities, USEPA Region 2 conducted a CERCLA removal action at the ECE property to remove and dispose of overburden soil and concrete contaminated with chromium (Cr) and other heavy metals, including cadmium, antimony, and lead. The boundaries of the excavation were limited to the ECE property overburden material (Weston Solutions, Inc. 2014). In support of developing remedial alternatives, two additional studies, including an aquifer test and an in situ reduction pilot study, were carried out following the removal action.

USEPA is now looking to implement a remedial action that will significantly reduce the mass of remaining contamination within the source area and reduce Cr(VI) concentrations to the extent practicable in the downgradient groundwater plume.

Remedial Action Objectives

The remedial action objectives (RAOs) for the site are as follows:

- **RAO 1.** Restore groundwater to beneficial use where Cr concentrations exceed the New Jersey Groundwater Quality Standard (GWQS). .
- **RAO 2.** Prevent ingestion of groundwater with Cr concentrations above New Jersey GWQS.
- **RAO 3.** Minimize the potential for infiltration of Cr(VI)-contaminated groundwater into basements and transfer of Cr(VI) onto basement surfaces.
- **RAO 4.** For basement surfaces contaminated by groundwater infiltration, prevent direct contact and ingestion of Cr(VI) concentrations on basement surfaces that exceed USEPA's acceptable risk range.

Development and Application of Preliminary Remediation Goals

The preliminary remedial goals (PRGs) for the site are as follows:

- Groundwater: 70 micrograms per liter (µg/L)
- Soils within the ECE Property (vadose zone): 20 milligrams per kilogram (mg/kg)
- Basement—High Use: 110 micrograms per cubic meter (µg/m^3) or 1.1 microgram (µg) per wipe
  - Exposure time: 8 hours for soft surface (6 hours for ages 7 to 18); 4 hours for hard surface (2 hours for ages 7 to 18)
  - Exposure duration: 350 days per year for 30 years
- Basement—Low Use: 870 µg/m^3 or 8.7 µg/wipe
  - Exposure time: 150 minutes per day (60 minutes/day ages 0 to 10)
  - Exposure duration: 5 days per week (2 days/week ages 6 to 18)

Identification and Screening of Remedial Technologies

Technology screening was conducted following the technology screening guidance described in the USEPA *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA 1988a). Potential remedial technologies and process options were screened according to the following three established criteria:

- Technical effectiveness
- Implementability
- Cost

Remedial technologies and process options that would not effectively address source area and downgradient plume contamination at the site were eliminated. The technologies and process options that were retained from the initial screening process were carried forward for developing remedial alternatives.

Technical Impracticability Determination

A technical impracticability (TI) waiver for the bedrock groundwater Cr(VI) plume ARARs at the site is appropriate, based on a TI evaluation performed using RI data collected at the site since 1983. The site-specific ARARs under the TI waiver would include the National Primary Drinking Water Standards maximum contaminant level for total Cr of 100 µg/L and the NJDEP GWQS Class IIA for total Cr of 70 µg/L.

The following conditions make restoration of the bedrock plume within a reasonable timeframe impracticable:

- The bedrock plume exists beneath highly urbanized and densely populated city areas that pose severe constraints on performing groundwater remediation.
- Available geochemical data indicate that MNA may not be a viable remedial strategy for the bedrock plume.

The bedrock groundwater flow system is very complex and heterogeneous, with numerous poorly connected fractures that may act as reservoirs for Cr(VI), as well as Cr(VI) in the rock matrix. As a result remediation of the bedrock plume using either pump and treat or in situ treatment would be difficult, as disconnected fracture networks and the rock matrix would not be remediated, likely resulting in contaminant rebound once active remediation ceases.

Modeling indicates that even with aggressive site remediation (source zone treatment and combined overburden and bedrock pumping), the predicted timeframe to achieve cleanup levels across the entire bedrock plume would be 250 years, which is not reasonable.

The results of the modeling indicate that the bedrock groundwater plume will neither increase nor decrease significantly in size for 10 to 15 years. After that time period, the plume will begin to decrease in size, primarily through dilution and dispersion, until the GWQS are achieved across the entire plume. As such, a defined TI zone for the bedrock groundwater plume can be established and maintained. Historical and future source remediation will further ensure that the bedrock plume will be stable or attenuate under a TI waiver. USEPA proposes a front-end TI waiver for the bedrock groundwater Cr(VI) plume. The proposed Alternative Remedial Strategy is institutional controls (ICs) and monitoring, which would be protective of human health and the environment.

Development and Screening of Remedial Alternatives

The descriptions of the remedial alternatives in this FS are conceptual and have been developed to a level of detail sufficient for the purposes of evaluating the alternatives against the National Contingency Plan (NCP) criteria, developing cost estimates of plus 50 to minus 30 percent accuracy, and comparing the alternatives. Per the NCP requirement, a no action alternative has been included and is carried through the entire FS process as the baseline condition against which the performance of the remaining alternatives are evaluated. The alternative selected for the site will be further developed during the remedial design process, and the specific methodologies and construction sequences used may change based on additional information that is gathered as part of predesign investigations.

The following alternatives were developed:

- Alternative 1: No Action
- Alternative 2: Source Treatment
  - 2A: Source treatment using soil mixing in the overburden and weathered bedrock, and pump and treat for the shallow bedrock.
  - 2B: Source treatment using in situ injections in the overburden and weathered bedrock, and pump and treat for the shallow bedrock.
  - Ongoing basement investigation and remedial actions including dewatering and cleaning/ waterproofing, as needed.
- Alternative 3: Source Treatment and In Situ Reduction Barriers for Overburden
  - Source zone treatment selected from Alternative 2
  - Creation of in situ reduction barriers in the downgradient overburden plume

- Alternative 4: Source Treatment and Pump and Treat for Overburden
  - Source zone treatment selected from Alternative 2
  - Extraction and ex situ treatment of groundwater with the opportunity for reinjection or discharge to publicly owned treatment works (POTW) or surface water body
- Alternative 5: Source Treatment, and combined Pump and Treat and In Situ Reduction Barriers for Overburden
  - Source zone treatment selected from Alternative 2
  - Extraction and ex situ treatment of groundwater with the opportunity for reinjection or discharge to POTW or surface water body
  - Creation of in situ reduction barriers in the downgradient overburden plume

The five alternatives were retained for further development and detailed evaluation. Both source treatment options under Alternative 2 were incorporated into Alternatives 3, 4, and 5 for comparison purposes, and Alternative 2A was assumed under Alternatives 3, 4, and 5 for developing cost estimates.

Evaluation of Remedial Alternatives

The NCP defines nine criteria, classified as threshold, balancing, or modifying, to be used for the detailed analysis of remedial alternatives. The remedial alternatives were evaluated against the first seven of nine criteria:

- Threshold criteria
  - Overall protection of human health and the environment
  - Compliance with applicable or relevant and appropriate requirements
- Balancing criteria
  - Long-term effectiveness and permanence
  - Reduction of toxicity, mobility, or volume through treatment
  - Short-term effectiveness
  - Implementability
  - Cost

The two modifying criteria—public and state acceptance—are used later in the process to evaluate the proposed remedy.

The detailed analysis was performed using a two-step process. During the first step, each alternative was evaluated individually against the NCP criteria. In the second step, a comparative analysis was performed using the same criteria to identify key differences between alternatives. Table ES-1 presents the results of the individual and comparative evaluation of the alternatives.

Table ES-1. Alternative Analysis Screening Against NCP Criteria

Garfield Groundwater Contamination Superfund Site

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	Alternative 1 No Further Action	Alternative 2A Source Treatment (Soil Mixing)	Alternative 2B Source Treatment (In Situ Injection)	Alternative 3 Source Treatment and In Situ Reduction Barriers for Overburden	Alternative 4 Source Treatment and Pump and Treat for Overburden	Alternative 5 Source Treatment and Pump and Treat with In Situ Reduction for Overburden
Threshold Criteria						
Overall Protection of Human Health and the Environment	1	3	3	3	4	4
	-Not protective since it allows for potential exposure to Cr through basement infiltration and future use of the aquifer. -Allows for unmonitored, potential further migration of groundwater contaminants.	-Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to Cr. -Source zone treatment would address the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period, but a longer period compared to Alternatives 3, 4, or 5.	-Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to Cr. -Source zone treatment would mitigate the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period, but a longer period compared to Alternatives 3, 4, or 5.	-Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to Cr. -Source zone treatment would mitigate the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period.	-Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to Cr. -Source zone treatment would mitigate the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period.	-Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to Cr. -Source zone treatment would mitigate the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period, but the shortest of any of the alternatives.
Compliance with ARARs	1	2	2	3	3	3
	-Since there is no action, ARARs for the source area and overburden plumes would not be met within a reasonable timeframe. -Based on groundwater modeling, achievement of the ARARs in the overburden plume would take hundreds of years.	-Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -Attenuation of the overburden plume is expected to occur through primarily dilution and dispersion. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.	-Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -Attenuation of the overburden plume is expected to occur through primarily dilution and dispersion. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.	-Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -In Situ reduction barriers would be designed and implemented to eventually meet overburden plume PRGs. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.	-Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -Pump and treat would be designed and implemented to eventually meet overburden plume PRGs. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.	-Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -Pump and treat combined with in situ reduction barriers would be designed and implemented to eventually meet overburden plume PRGs. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.
Balancing Criteria						
Long-Term Effectiveness and Permanence	N/A	2	2	3	3	4
	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	*Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps and sealants. -This alternative would permanently achieve PRGs in the overburden plume through dilution and dispersion. *Factors that may provide disadvantages in the long-term:* -Cr(VI) in poorly connected pores and immobile zones may delay achieving of PRGs within certain portions of the plume. -Long-term monitoring would be required for the groundwater plume.	*Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps, and sealants. -This alternative would permanently achieve PRGs in the overburden plume through dilution and dispersion. *Factors that may provide disadvantages in the long-term:* -Cr(VI) residing in poorly connected pores and immobile zones may result in difficult achievement of PRGs within certain portions of the plume. -Long-term monitoring would be required for groundwater plume.	*Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -In Situ reduction would permanently achieve PRGs in the overburden plume by reduction of Cr(VI) to Cr(III). -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps and sealants. *Factors that may provide disadvantages in the long-term:* -Rebound due to Cr(VI) in poorly connected pores and immobile zones would likely occur once injections are completed. -Long-term monitoring would be required to evaluate the long-term effectiveness of remediation in the groundwater plume.	*Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -Pump and Treat would achieve PRGs in the overburden plume by removing Cr(VI) from the groundwater and ex situ treatment. -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps, and sealants. *Factors that may provide disadvantages in the long-term:* -Rebound due to Cr(VI) in poorly connected pores and immobile zones would likely occur once pumping	*Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -Pump and treat with in situ reduction would achieve RAOs in the overburden plume through both reduction of Cr(VI) to Cr(III), and removal of Cr(VI) from groundwater and ex situ treatment. -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps, and sealants. *Factors that may provide disadvantages in the long-term:* -Rebound due to Cr(VI) in poorly

Table ES-1. Alternative Analysis Screening Against NCP Criteria
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	Alternative 1 **No Further Action**	**Alternative 2A** **Source Treatment (Soil Mixing)**	**Alternative 2B** **Source Treatment (In Situ Injection)**	**Alternative 3** **Source Treatment and In Situ Reduction Barriers for Overburden**	**Alternative 4** **Source Treatment and Pump and Treat for Overburden**	**Alternative 5** **Source Treatment and Pump and Treat with In Situ Reduction for Overburden**
		-Long-term enforcement of ICs would be required to mitigate risk.	-Long-term enforcement of ICs would be required to mitigate risk.	-Long-term enforcement of ICs would be required to mitigate risk.	stops. -Pumps would need to be repaired/replaced and wells would need to be rehabilitated routinely to maintain mass removal. -Long-term monitoring would be required to evaluate the long-term effectiveness of remediation in the groundwater plume. -Long-term enforcement of ICs would be required to mitigate risk.	connected pores and immobile zones would likely occur once pumping stops. -Pumps would need to be repaired/replaced and wells would need to be rehabilitated routinely to maintain mass removal. -Long-term monitoring would be required to evaluate the long-term effectiveness of remediation in the groundwater plume. -Long-term enforcement of ICs would be required to mitigate risk.
Reduction of Toxicity, Mobility, or Volume (TMV) through Treatment	N/A	2	2	3	3	4
	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	-Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -Reduction in toxicity and volume of the plume is achieved primarily through dilution and dispersion as groundwater flows downgradient.	-Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -Reduction in toxicity and volume of the plume is achieved primarily through dilution and dispersion as groundwater flows downgradient.	-Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -In Situ reduction would permanently reduce Cr(VI) in the plume, reducing both toxicity and mobility.	-Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -Pump and treat would permanently remove Cr(VI) in the plume, reducing toxicity and volume.	-Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -In Situ reduction would permanently reduce Cr(VI) in the plume, reducing both toxicity and mobility. -Pump and treat would permanently remove Cr(VI) in the plume, reducing toxicity and volume.
Short-Term Effectiveness	N/A	3	3	3	4	3
	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	*Factors expected to perform well in the short-term:* -Soil mixing would remediate source area overburden within one year. -Fewer impacts on the community and risks to workers would be expected, since no active remediation would be implemented outside source area. *Factors that may provide disadvantages in the short-term:* -There is possible risk to workers dealing with hazardous chemicals during source treatment. -Excavation, stockpiling, and soil mixing would require heavy equipment on the ECE property, which would cause noise and air pollution and could be disruptive to the surrounding community. -Greenhouse gases (GHG) are primarily generated during equipment operation and long-term transportation of large quantities of substrate. -No active treatment in the overburden plume would limit short-term effectiveness.	*Factors expected to perform well in the short-term*: -In Situ reduction within the source area overburden and shallow bedrock would become effective at reducing Cr(VI) to Cr(III) once reducing conditions are established in the subsurface following initial injections. - Fewer impacts on the community and risks to workers would be expected, since no active remediation would be implemented outside source area. *Factors that may provide disadvantages in the short-term:* - In Situ injections would remediate source area overburden, but may require multiple injections over approximately 6 years to maintain reagent distribution. -GHG are primarily generated during source zone treatment, well installation, and long-term transportation of large quantities of substrate. -There is possible risk to workers dealing with hazardous chemicals during source treatment. -No active treatment in the overburden plume would limit short-term effectiveness.	*Factors expected to perform well in the short-term:* -In situ reduction within the source area overburden and shallow bedrock would become effective at reducing Cr(VI) to Cr(III) once reducing conditions are established in the subsurface following initial injections. *Factors that may provide disadvantages in the short-term:* -90 percent reduction of the overburden plume area would take more than 100 years, providing little short-term effectiveness. -More disruptions to surrounding community would occur due to installation of over 200 injection wells. -GHG are primarily generated during source zone treatment, well installation, and long-term transportation of large quantities of substrate. -There is possible risk to workers dealing with hazardous chemicals during source overburden treatment. -The mobilization of reduced metals (e.g., iron, manganese, and arsenic) in the aquifer would need to be considered and monitored	*Factors expected to perform well in the short-term:* -In situ reduction within the source area overburden and shallow bedrock would become effective at reducing Cr(VI) to Cr(III) once reducing conditions are established in the subsurface following initial injections. -Less disruptions to surrounding community would occur during installation of pump-and-treat system compared to installing in situ injection wells. *Factors that may provide disadvantages in the short-term:* -90 percent reduction of the overburden plume area would take more than 100 years, providing little short-term effectiveness. -GHG are primarily generated during source zone treatment and operation of groundwater treatment system. -There is possible risk to workers dealing with hazardous chemicals during source overburden treatment.	*Factors expected to perform well in the short-term:* -In situ reduction within the source area overburden and shallow bedrock would become effective at reducing Cr(VI) to Cr(III) once reducing conditions are established in the subsurface following initial injections. *Factors that may provide disadvantages in the short-term:* -Active treatment in the groundwater overburden would result in 90 percent reduction of the overburden plume area within 90 years, providing the best option, but still little short-term effectiveness. -More disruptions to surrounding community would occur due to installation of over 200 injection wells. -GHG are primarily generated during source zone treatment, well installation, long-term transportation of large quantities of substrate, and operation of groundwater treatment system. -There is possible risk to workers

Table ES-1. Alternative Analysis Screening Against NCP Criteria

Garfield Groundwater Contamination Superfund Site

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	Alternative 1 No Further Action	Alternative 2A Source Treatment (Soil Mixing)	Alternative 2B Source Treatment (In Situ Injection)	Alternative 3 Source Treatment and In Situ Reduction Barriers for Overburden	Alternative 4 Source Treatment and Pump and Treat for Overburden	Alternative 5 Source Treatment and Pump and Treat with In Situ Reduction for Overburden
				during implementation of the in situ reduction barriers.		dealing with hazardous chemicals during source overburden treatment. -The mobilization of reduced metals (e.g., iron, manganese, and arsenic) in the aquifer would need to be considered and monitored during implementation of the in situ reduction barriers.
Implementability	N/A	4	4	2	3	2
	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	<u>*Factors expected to perform well for implementation:*</u> -Conventional equipment and vendors could be used for implementation of active treatment elements. -All aboveground structures on the ECE property have been removed. -No offsite active treatment would be performed within the overburden plume, resulting in little disturbance to the community. <u>*Factors that may provide disadvantages for implementation:*</u> -Source soil mixing actions may be constrained due to the limited space within the ECE property and site traffic control issues.	<u>*Factors expected to perform well for implementation:*</u> -Conventional equipment and vendors could be used for implementation of active treatment elements. -All aboveground structures on the ECE property have been removed. -No offsite active treatment would be performed within the overburden plume, resulting in little disturbance to the community.	<u>*Factors expected to perform well for implementation:*</u> -Conventional equipment and vendors could be used for implementation of active treatment elements. <u>*Factors that may provide disadvantages for implementation:*</u> -Community would be disturbed over a large area due to installation of over 200 injection wells, and transport, delivery, and storage of large amounts of substrate for ongoing injections. -Construction period would be extended due to the number of injection wells to be installed. -Right-of-way permits would be required for well installation and multiple injection events from the City of Garfield.	<u>*Factors expected to perform well for implementation:*</u> -Conventional equipment and vendors could be used for implementation of active treatment elements. <u>*Factors that may provide disadvantages for implementation:*</u> -Community would be disturbed over a large area due to installation of pump-and-treat system piping and wells. -Right-of-way permits would be required for well installation from the City of Garfield. -Permits would be required for discharge of treated water.	<u>*Factors expected to perform well for implementation:*</u> -Conventional equipment and vendors could be used for implementation of active treatment elements. <u>*Factors that may provide disadvantages for implementation:*</u> -Community would be disturbed over a large area due to installation of over 200 injection wells, and pump-and-treat system piping and wells, and transport, delivery, and storage of large amounts of substrate for ongoing injections. -Construction period would be extended due to the number of injection wells to be installed. -Right-of-way permits would be required for well installation and multiple injection events from the City of Garfield. -Permits would be required for discharge of treated water.
Cost	$0	$13,937,000	$10,197,000	$37,334,000	$22,088,,000	$49,112,000

Notes:

1 - Alternative does not meet the criterion and has disadvantages or uncertainty
2 - Alternative is expected to perform poorly against the criterion and may have disadvantages or uncertainty
3 - Alternative is expected to perform moderately well against the criterion but with some disadvantages or uncertainty
4 - Alternative is expected to perform well against the criterion with few to no apparent disadvantages or uncertainty
5 - Alternative is expected to perform very well against the criterion with no apparent disadvantages or uncertainty

ARARs - applicable or relevant and appropriate requirements
Cr(VI) - hexavalent chromium
Cr(III) - trivalent chromium
ECE - E.C. Electroplating, Inc.
GHG - greenhouse gas

ICs - institutional controls
N/A - not applicable
NCP - National Oil and Hazardous Substance Pollution Contingency Plan
PRG - preliminary remediation goal
RAO - remedial action objective
TMV - toxicity, mobility, or volume

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Acronyms and Abbreviations

˚F	degrees Fahrenheit
µg	microgram
µg/L	micrograms per liter
$µg/m^3$	micrograms per cubic meter
3D	three-dimensional
amsl	above mean sea level
ARAR	applicable or relevant and appropriate requirement
ARS	Alternative Remedial Strategy
ATSDR	Agency for Toxic Substances and Disease Registry
BERA	baseline ecological risk assessment
bgs	below ground surface
CaSx	calcium polysulfide
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	*Code of Federal Regulations*
CH2M	CH2M HILL
COC	contaminant of concern
Cr	chromium
Cr(III)	trivalent chromium
Cr(VI)	hexavalent chromium
CSM	conceptual site model
CTM	contaminant transport model
dBA	A-weighted decibels
DO	dissolved oxygen
DSW	discharge to surface water
ECE	E.C. Electroplating
EVO	emulsified vegetable oil
FHCP	FLUTe hydraulic conductivity profiling
FS	feasibility study
ft/d	feet per day
ft/ft	foot per foot
ft^2/d	square feet per day
GFM	groundwater flow model

GHG	greenhouse gas
gpm	gallons per minute
GRA	general response action
Guelph	University of Guelph
GWQS	groundwater quality standards
$H_2Cr_2O_7$	chromic acid
H_2SO_4	sulfuric acid
HazMat	hazardous materials
HHRA	human health risk assessment
HI	hazard index
HTRW	hazardous, toxic, and radioactive waste
IC	institutional control
L/kg	liters per kilogram
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
$MgSO_4 \cdot 7H_2O$	magnesium sulfate
MLU	multilayer unsteady state
MNA	monitored natural attenuation
mV	millivolts
MVS	Mining Visualization System
NAVD88	North American Vertical Datum of 1988
NAWC	Naval Air Warfare Center
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NJAC 7:14A-12 Effluent Standards	NJAC 7:14A-12 Effluent Standards Applicable to Direct Discharges to Surface Water and Indirect Discharges to Domestic Treatment Works
NJAC	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJDHSS	New Jersey Department of Health and Senior Services
NJPDES	New Jersey Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	operations and maintenance
OMB	Office of Management and Budget
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response

POTW	publicly owned treatment works
PRB	permeable reactive barrier
PRG	preliminary remedial goal
PVSC	Passaic Valley Sewerage Commission
RAB	removal action branch
RAL	removal action level
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RSL	regional screening level
RTA	remediation target area
RTF	remediation timeframe
SARA	Superfund Amendments and Reauthorization Act
SGBR	subgrade bioreactor
site	Garfield Groundwater Contamination Superfund Site in the city of Garfield, Bergen County, New Jersey
SLERA	screening-level ecological risk assessment
Step 3 BERA	step 3 baseline ecological risk assessment
Superfund	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
TBC	to-be-considered
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TI Guidance	USEPA OSWER Directive 9234.2-25, *Guidance for Evaluating the Technical Impracticability of Groundwater Restoration*
TI	Technical Impracticability
TMV	toxicity, mobility, or volume
UIC	Underground Injection Control
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UST	underground storage tank
ZVI	zero-valent iron

SECTION 1

Introduction

1.1 Purpose

This draft feasibility study (FS) report was prepared for the U.S. Army Corps of Engineers (USACE), Kansas City District, and the U.S. Environmental Protection Agency (USEPA) Region 2 by CH2M HILL (CH2M) to present the results of the feasibility analysis of remedial alternatives for the Garfield Groundwater Contamination Superfund Site in the city of Garfield, Bergen County, New Jersey (site). This FS report has been prepared under USACE, Kansas City District Hazardous, Toxic, and Radioactive Waste (HTRW) Contract Number W912DQ-11-D-3005, Task Order 0003.

The site is in the southwestern portion of the city of Garfield in Bergen County, New Jersey, among a mix of residential and commercial properties (Figure 1-1). The site consists of hexavalent chromium [Cr(VI)] soil contamination at the E.C. Electroplating, Inc. (ECE) property and downgradient Cr(VI) groundwater plumes in the overburden and bedrock originating from the ECE property at 125 Clark Street and extending west under the Passaic River into the city of Passaic, north to Belmont Avenue, and south to Somerset Street (Figure 1-2).

The site (USEPA Comprehensive Environmental Response, Compensation, and Liability Information System ID NJN000206317) is on the National Priorities List (NPL) of hazardous substances, pollutants, or contaminants sites that require further evaluation. Accordingly, USEPA Region 2 performed a remedial investigation (RI) according to the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, or “Superfund”), as amended. The RI was completed between 2011 and 2013, and the results presented in a Remedial Investigation Report (CH2M 2014a).

This FS focuses on remedial alternatives for Cr(VI) source area soil and the associated Cr(VI) plumes in the overburden and bedrock aquifers that extend west under the Passaic River. The FS is being prepared according to the requirements of CERCLA, as amended.

1.2 Report Organization

This FS develops and evaluates remedial alternatives that will reduce or eliminate unacceptable risks to human health and the environment from exposure to contaminated groundwater on the ECE property and in the downgradient plumes. The FS was prepared following USEPA’s *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA 1988a). The report is organized into the following sections:

1. **Introduction**. Briefly describes the regulatory framework, FS purpose and organization, and site background and setting.
2. **Remedial Investigation Activities and Conceptual Site Model.** Summarizes the results of historical investigations, the RI, aquifer study, pilot study, and ongoing investigation work; presents a conceptual site model (CSM) for the site, including results of the fate and transport model; and summarizes the ecological and human health risk assessment findings.
3. **Removal Actions:** Summarizes the results of historical actions at the site, including basement inspections and removal actions, ECE property hazardous materials removal action, ECE property aboveground infrastructure demolition, and ECE property soil removal actions.
4. **Development and Application of Remediation Goals**. Presents the remedial action objectives (RAOs) and remediation goals for the site, and summarizes the potential applicable or relevant and appropriate requirements (ARARs). This section also identifies the areas and depths of groundwater to be targeted by the remediation.

5. **Identification and Screening of Remedial Technologies.** Identifies and describes a range of remedial approaches, technologies, and process options that could be used to address groundwater contamination, and screens them based on effectiveness, implementability, and cost.
6. **Technical Impracticability (TI).** Provides the justification and supporting documentation to support a TI waiver being issued by USEPA for the bedrock plume at the site.
7. **Development and Evaluation of Remedial Alternatives**. Develops remedial alternatives for groundwater by combining the remedial approaches, technologies, and process options that were retained after the screening described in Section 5; screens the alternatives based on effectiveness, implementability, and cost; and presents detailed individual and comparative analyses of the remedial alternatives that were retained using the evaluation criteria defined in the National Oil and Hazardous Substance Pollution Contingency Plan (NCP).
8. **References**. Provides the references cited in this report.

The report appendixes provide supporting information as follows:

A—Aquifer Test and Pilot Test Technical Memorandums
B—Removal Action Reports
C—Groundwater Modeling Results
D—Estimated Costs

1.3 Site Background

The following is a description of the site setting, the history of site use, and potential sources of contamination.

1.3.1 Site Location and Description

The site is located primarily in the southwestern portion of the city of Garfield in Bergen County, New Jersey, among a mix of residential, industrial, and commercial properties (Figure 1-2). The source area has been identified as the former ECE facility at 125 Clark Street in Garfield, which occupies Block 38.01, Lots 8, 11, and 15 (Figure 1-2). The former ECE property covers approximately 0.65 acre. Electroplating process buildings, shown in Figure 1-3, occupied the majority of the property before October 2012, when USEPA demolished them. There was a small paved parking area along Clark Street and another small yard at the southeastern corner of the site. The vacant ECE property is surrounded by a mixture of commercial, industrial, and residential properties.

The current boundaries of the overburden and bedrock groundwater contamination plumes study area, which defines the extent of the site, are from the former ECE property on the east, extending west past the Passaic River to the city of Passaic, Passaic County, New Jersey, north to Belmont Avenue, and south to Somerset Street (Figure 1-2).

1.3.2 Demographics and Land Use

1.3.2.1 City of Garfield

The city of Garfield covers approximately 2 square miles in area and was originally incorporated in 1898 as a borough and then as a city in 1917. The following demographics were obtained from the 2010 U.S. Census: Garfield is home to approximately 30,500 residents; the median age of the community is approximately 36 years. The population density is roughly 14,525 people per square mile, with a racial makeup consisting of 76.73 percent White, 6.5 percent African American, 0.43 percent Native American, 2.22 percent Asian, 0.01 percent Pacific Islander, 10.85 percent other races, and 3.26 percent from two or more races. Hispanics and Latinos of any race account for 32.24 percent of the population. The median household income was $51,407, and the median family income was $56,701. Approximately 9.8 percent of families, and 13.0 percent of the population, live below the poverty line (U.S. Census Bureau 2010). The languages commonly spoken are English, Spanish, Polish, and Macedonian. As of the 2000 Census, approximately 25 percent of Garfield's population was listed as being of Polish ancestry, ranked third-highest in New Jersey (U.S. Census Bureau 2000).

The city of Garfield is highly urbanized and is composed of residential neighborhoods, local government buildings, and commercial properties. Based on a review of current aerial maps, the majority of the properties within the plume boundary are developed, with little to no public green space or parks. One notable feature located near the site is Roosevelt School #7 on Lincoln Place, between Clark Street, and Frederick Street.

The City of Garfield provides public water supplied by production wells in Elmwood Park, New Jersey, and treated water purchased from the Passaic Valley Water Commission. No known active water supply wells are located within Garfield, although a network of currently inactive city supply wells is present north of the study area as shown in Figure 1-2 (Weston Solutions, Inc. 2010).

1.3.2.2 City of Passaic

The site extends into the eastern portion of the city of Passaic, which according to the 2010 U.S. Census, has a population of approximately 70,000 in 19,000 households within a total area of 3.2 square miles. The racial makeup of the city, according to the U.S. Census Bureau (2010) was 45.06 percent white, 10.64 percent African American, 1.07 percent Native American, 4.36 percent Asian, 0.04 percent Pacific Islander, 33.37 percent from other races, and 5.47 percent from two or more races. Hispanic or Latinos of any race were 71.02 percent of the population.

A search of New Jersey Department of Environmental Protection (NJDEP) records of potential water supply wells located in Passaic was performed in 2013, and no water supply wells were identified. The city of Passaic drinking water supply is purchased as treated water from the Passaic Valley Water Commission.

1.3.3 Site History

ECE was founded in the late 1930s and was privately owned and operated at the site until ceasing operations on March 3, 2009. Prior to ownership by ECE, the site was used as a machine shop and housed chicken coops (Chapin Engineering 2009).

Under ECE ownership, the property was used as a custom metal plating shop serving specialized industries such as plastic, paper, and film. Both electric and electroless plating processes were used to deposit a metal veneer on the surface of machined parts, primarily to provide corrosion and wear protection. Over its operating life, the facility electroplated and cylindrically ground chromium (Cr), electrically plated copper, and electrolessly plated nickel onto machined parts (Chapin Engineering 2009).

The full building layout evolved over time, with different buildings established during different eras of operation and the last upgrades made 32 years before ceasing operations. A 7,900-gallon vertical storage tank at the site was historically used to store chromic acid plating solution. Three additional vertical tanks (Tank #1, #2, and #3) also were used to periodically store chromic acid and copper-based solutions throughout the operational history of the facility (Figure 1-3) (Chapin Engineering 2009). In October 2012, USEPA completed demolition of all aboveground facilities, as detailed in Section 3.2.

1.3.4 Historical Potential Sources of Contamination

A number of potential historical sources of contamination have been identified at the ECE property, and there are two documented spills at the site.

In December 1983, the flange at the bottom of the 7,900-gallon vertical storage failed, releasing an estimated 3,640 gallons of chromic acid directly into the shallow aquifer. The spill was reported to NJDEP and the Garfield Fire Department (spill #83-12-15-1400 and 93-10-13-1102). Following the spill, a groundwater recovery well was installed and operated for 4 months, during which approximately 29 percent of the spilled mass of Cr was recovered (Princeton Aqua Science 1984). Based on diminishing recovery of Cr mass, and suspected contaminant migration into bedrock, the system was shut down with concurrence from NJDEP in April 1985 (Chapin Engineering 2009).

In May 1996, an additional spill was reported at the ECE facility in which approximately 250 gallons of process wastewater flowed from the building onto Sherman Place. The spill was reported to NJDEP (spill #96-05-02-0813-27 and 96-05-02-0806-18), and the Bergen County hazardous materials (HazMat) team responded and mitigated the spill using absorbent pads. ECE personnel disposed of the pads with other Cr-contaminated materials (masking plastic). No follow-up by facility personnel was requested by the HazMat team.

In 2013, Mining Visualization System (MVS) software was used to prepare a three-dimensional (3D) model of the Cr(VI) plume and provide an order-of-magnitude approximation of the mass present in the plume resulting from releases at the ECE property. The MVS model results suggest that the current mass of Cr(VI) in the groundwater plume may be up to four times the amount reportedly released during the 1983 and 1996 spills, indicating that unreported spills or leaks may have occurred historically at the former ECE facility (CH2M 2014a).

One additional historical potential source of contamination is the T.A. Farrell Electroplating Facility, a separate former electroplating facility located approximately 1,600 feet to the southwest, downgradient and crossgradient of the ECE property (Figure 1-2). The T.A. Farrell site operated as an electroplating facility between at least 1972 and January 1989, when a fire stopped most operations at the facility. Historically, no releases of Cr were reported at the T.A. Farrell Electroplating Facility. However, in 2007, an RI report for the T.A. Farrell Electroplating Facility indicated that total Cr exceeded criteria in 3 of 17 groundwater samples. Samples were not analyzed for Cr(VI) (NJDEP 2007a). A select number of onsite T.A. Farrell wells are part of the overall monitoring well network associated with the ECE site.

1.4 Physical Characteristics of the Site

This section summarizes the regional and local physical characteristics of the site and surrounding area, including surface features and topography, climate, geology, and hydrogeology.

1.4.1 Surface Features and Topography

The site is positioned within a highly urbanized area of the Saddle River watershed, which regionally empties into the Passaic River. The Saddle River watershed topography ranges from approximately 5 to 100 feet above mean sea level (amsl). The topography in the city of Garfield slopes downward to the west toward the Passaic River, which lies near sea level; however, development of the area has altered the original topography. The former ECE facility is located on a low-lying hill, approximately 50 feet amsl and 1 mile east of the Passaic River. The site topography is shown in Figure 1-1, and the approximate boundaries of the site and relevant site landmarks are shown in Figure 1-2.

A tributary stream to the Passaic River in the site vicinity was filled in the early 1900s as the area became increasingly developed (Lockheed Martin Technology Services 2010). The approximate location of the former tributary is shown in Figure 1-2.

1.4.2 Climate

The climate in Garfield is consistent with northeastern temperate climates. Temperature ranges are generally moderated by the Atlantic Ocean and average 73 degrees Fahrenheit (˚F) in July and 32 ˚F in December (Rutgers 2013). In 2011, nearby Newark International Airport reported 283 days with less than 0.1 inch of precipitation and 82 days with precipitation equal to or greater than 0.1 inch, according to the National Climate Data Center division of the National Oceanic and Atmospheric Administration (2013). On average, Garfield receives 49.13 inches of precipitation each year, which is slightly above the average 48.64 inches of precipitation experienced across the state.

1.4.3 Geology

1.4.3.1 Regional Geology

The overburden material underlying the region consists of a thick (generally 60- to 80-foot) layer of unconsolidated sediments including (from oldest/deepest to youngest/shallowest) Pleistocene periglacial deposits, including till and fluvial drift; recent fluvial deposits; and anthropogenic fill. Glacial sediments that were deposited throughout the region during the Pleistocene glaciation consist of both terminal moraines (till) and glaciofluvial (drift) deposits (Nichols 1968). Glaciofluvial deposits, or deposits from streams and rivers laden with sediment from melting glaciers, are generally well-stratified and composed of laminar beds of sand and gravel or silt and clay. Unlike fluvial river deposits, the terminal moraines are unstratified till deposits composed of a heterogeneous mixture of clay, silt, sand, gravel, and boulders (Nichols 1968). An erosional unconformity consisting of a coarse-grained channel lag overlying the weathered bedrock separates the glacial deposits and the underlying Newark Basin Supergroup bedrock (Newark Group).

The Newark Group was formed as a result of rifting during the widening of the Atlantic Ocean. It consists of multiple depositional cycles of late Triassic to early Jurassic fluvial and lacustrine sedimentary deposits (Morin et al. 2000). The Newark Group is primarily composed of sedimentary rocks consisting of sandstones, shales, mudstones, and conglomerates. However, three basalt flows were extruded onto the late Triassic and early Jurassic paleosurfaces. These formations lie west of Garfield. The regional bedrock geologic setting of the site is shown in Figure 1-4.

The sedimentary rocks of the Newark Group have been divided into three formations on the basis of distinctive lithology. These units consist of, from oldest to youngest, the Stockton Formation, composed largely of medium- to coarse-grained sandstones with inclusions of mudstone and siltstone; a middle unit, the Lockatong Formation, generally composed of gray and black siltstones and mudstones; and an upper unit, the Passaic Formation, composed largely of reddish-brown mudstones, siltstones, sandstones, and conglomerates. The site is within the Passaic Formation, which represents the late Triassic and early Jurassic ages. The Passaic Formation is several thousand feet thick and is underlain by the Lockatong and Stockton formations (Olsen 1980).

1.4.3.2 Site Geology

The site geology was characterized during the RI through logging of subsurface materials in both the overburden and the bedrock throughout the groundwater study area. Additional information from historic boreholes installed within the former ECE, T.A. Farrell, and Kalama Chemical properties (Raritan Enviro Sciences, Inc. 1997) was incorporated during the RI. A full description of the site geology was included in the final RI report (CH2M 2014a)

Geologic cross sections were generated depicting the vertical sequence of materials underlying the site based on boring logs and downhole geophysical logs. Figure 1-5 is a site plan showing the locations of the cross sections, and Figures 1-6 through 1-8 depict cross sections from west to east, southwest to northeast, and south to north, respectively.

The geologic cross sections provide a two-dimensional representation of the subsurface lithology, concentrations of Cr(VI) at each well, and fracture tadpole plots at select bedrock borings. As shown in the cross sections and detailed in the following subsections, the sand and gravel glacial deposits of the overburden material and the underlying weathered and interbedded competent bedrock layers of mudstone, siltstone, and sandstone are consistent with regional geology. A layer of weathered bedrock was present across much of the site between the overburden and bedrock formation.

Cross section A-A’ (Figure 1-6) is oriented from west to east across the site paralleling Willard Street. To the west, the cross section shows geologic conditions from monitoring wells EPA-26-BR and extends past the ECE facility to eastern monitoring wells EPA-14-OB and EPA-14-BR. The bedrock topography generally follows surface topography and trends downward towards the west. The bedrock surface is overlain by glacial sands and trace clay material with unstratified lenses of clay and gravel, followed by an approximate 7- to 20-foot layer of fill, all of which together represent the unconsolidated overburden. Immediately below the overburden is a layer of weathered sandstone, siltstone, and mudstone. The degree of weathering is highly variable, with the thickest weathered deposits towards the west at approximately 60 feet thick, and the thinnest towards the eastern portion of the site beneath ECE.

Cross section B-B' (Figure 1-7) extends from the southwest at well EPA-27-BR and runs to the northeast, ending at wells EPA-14-BR and EPA-14-OB. The overburden at well EPA-27-BR is approximately 60 feet thick and is underlain by approximately 50 feet of weathered sandstone and mudstone. Towards the center of B-B', at well EPA-06-OB, lies 40 feet of overburden underlain by 35 feet of variably weathered sandstone and mudstone.

Cross section C-C' (Figure 1-8) begins at the southern portion of the site at EPA-11-OB and extends nearly due north, ending at Garfield municipal well GAR-1A-BR. The bedrock along C-C' mirrors the topography and slopes downwards towards the south. The overburden at well EPA-11-OB is approximately 30 feet thick, and at EPA-20-BR to the north it is approximately 50 feet thick.

Site Overburden Geology

In the overburden soil, historical industrialization and residential construction have modified subsurface conditions, resulting in a reworked fill layer from ground surface to 7 feet below ground surface (bgs) on average, with a maximum observed thickness of 36 feet (EPA-27-OB). The thickness of the surficial deposits is often augmented by the emplacement of anthropogenic fill to recontour depressed areas for construction. In addition, to displaced and reworked native soils, the fill is often composed of industrial byproducts such as fly ash, cinders, and demolition debris.

Beneath the surficial layer of fill is a layer of unstratified glacial deposits of varying thickness, consisting mainly of sands, silty sands, gravels, trace silt and clay, with an approximate range of thickness of 10 to 90 feet. The stratified drift generally increases with depth from the east, near the ECE property, to the west, with the greatest thickness observed west of the Passaic River (Figure 1-6). The stratified drift thickness remains generally the same from north to south with a decrease in thickness where bedrock is encountered at shallower depths (Figure 1-8).

Soils were classified using the unified soil classification system and typically consisted of a yellowish to reddish-brown fine to coarse silty sand (SM) and well-graded, fine to coarse sand (SW). Fine to coarse, subangular to subrounded gravel was commonly encountered throughout the site and in varying degrees of thickness and frequency. Thin, discontinuous units of silt and clay were observed sporadically in overburden borings.

A transitional layer of weathered bedrock exists below the overburden materials, ranging from non-existent east of the ECE property (EPA-14-BR) up to approximately 50 feet thick (EPA-04-BR, EPA-20-BR and EPA-27-BR) (Figures 1-6 through 1-8). The geology of the weathered zone consists mainly of weathered argillaceous and micaceous fine-grained grayish red to reddish brown sandstone, siltstones, and mudstones. Angular to subrounded gravel units and cobbles were also observed, along with evidence of vertical fractures. The presence of the weathered bedrock layer is more consistent to the north and west of the ECE property, becoming intermittent to the south.

Within the ECE property, the overburden geology is similar to that observed throughout the overall plume footprint, as observed in the soil borings advanced in support of the 2014 in situ pilot study (Section 2.2.3). The overburden soil was observed as reworked fill with varying thickness between 2 and 10 feet from the ground surface, within the ECE property boundary. Underlying the fill, unstratified glacial deposits were observed consisting mainly of sands, silty sands, and silts to an approximate average depth of 20 feet bgs. Beneath the glacial deposits, the top of the weathered bedrock was observed in soil borings EPA-30-OB and EPA-32-OB. Based on historic soil borings (EPA-10-BR), the weathered bedrock on the ECE property varies in thickness from nonexistent to approximately 6 feet from east to west across the site. In 2014, USEPA conducted a source area vadose zone excavation, removing impacted soils within the ECE property down to varying depths, with the maximum excavation reaching 14 feet bgs, as described in Section 3.2. The excavated area was backfilled with coarse grain sand and gravel material.

Site Bedrock Geology

Bedrock from the Passaic Formation underlying the site consisted of thinly interbedded micaceous siltstones, mudstones, and fine- to medium-grained sandstones with minor occurrences of rounded, fine- to coarse-grained sandstones. Rock colors exhibited a wide range of tones and shades of red. An analysis of the geophysical log from well EPA-18-BR, located near the center of the site, shows an average bedding strike of 145° southeast, dipping at 14° southwest.

In addition to abundant mechanical breaking that predominantly occurred along bedding partings, frequent fractures were observed in rock cores from the site. The natural fractures are generally highly weathered with staining from mineral oxidation along the margins of the fracture, suggesting water migration through the fractures. Many fractures are partially to completely infilled with white mineralization, possibly calcite. Fracture inclination ranged from near-horizontal (0°) to subvertical (70°).

Natural gamma ray responses from downhole geophysical logs indicate the presence of three discrete sandstone units (upper, middle, and lower sandstones) across the site. The upper sandstone averaged 9 feet in thickness, the middle unit averaged 6 feet in thickness, and the bottom unit had an average thickness of 15 feet. These three sandstone units are shown on the cross sections to illustrate the stratigraphy within the bedrock, including apparent dip of the bedrock (Figures 1-6 through 1-8). Each layer appears to dip at an angle consistent with regional bedding, with the dip consistently increasing to the west.

Increased fracture density at the contacts between the sandstone and surrounding finer-grained rocks were observed in acoustic televiewer logs. Caliper logs express these contacts by showing greater borehole diameter, suggesting open fracture apertures in combination with the greater fracture density. These log signatures may indicate a stronger fracturing at these intervals, and therefore greater potential for groundwater flow and solute transport.

1.4.4 Hydrogeology

1.4.4.1 Regional Hydrogeology

Groundwater occurs within two hydrogeologic systems in this region—the unconsolidated overburden materials and the fractured sedimentary rock composing the Brunswick aquifer. The unconfined water table is generally encountered at less than 20 feet bgs in the unconsolidated overburden, although it can be as deep as 66 feet bgs. Groundwater flow in the overburden materials is predominantly controlled by local topography. Recharge may occur as a result of direct precipitation or runoff infiltration.

The saturated thickness of the overburden aquifer is variable, depending on the thickness of surficial deposits. Based on geological logs created within the site, the saturated thickness of the unit varies from approximately 5 to 70 feet within the city of Garfield, and between 10 and 30 feet within the groundwater plume boundaries. The hydraulic conductivity of materials in the overburden aquifer, as reported in literature for similar medium- to fine-grained sands, ranges from 1 to 100 feet per day (3.5×10^{-4} to 3.5×10^{-2} centimeters per second) (Walton 1989).

Glacial drift deposits of the overburden recharge the underlying leaky confined aquifers of the Brunswick aquifer contained in the Passaic Formation. At the top of the Passaic Formation, bedrock has undergone prolonged weathering, resulting in a groundwater flow that follows the topographic slope and displays hydraulic behavior equivalent to porous media (Herman 2001). Regionally, vertical hydraulic conductivity in this weathered interval has been reported at up to two orders of magnitude greater than the hydraulic conductivity of similar rock types in the deep, unweathered portions of the bedrock aquifer (Lewis-Brown and Jacobsen 1995).

Below the weathered zone, there is little primary porosity in the formation; therefore, groundwater flow is controlled by high-angle fractures and subhorizontal bedding plane partings found in the rock matrix. The movement of groundwater within these fractures and bedding plane partings depends on the hydraulic gradient and orientation, and effective apertures of the open fractures. As noted previously, many fractures are filled with materials from overlying soils as well as clays and silts generated by weathering of the bedrock. Where conductive fractures are encountered, production wells display yields ranging from 50 to close to 600 gallons per minute (gpm). Upper bedrock zones display limited anisotropy, while deeper flow zones typically exhibit anisotropic hydraulic responses under pumping conditions, with the maximum hydraulic conductivity oriented subparallel to the strike of bedding. The transmissivity estimated from the specific capacity (Kasenow and Pare 1995) of local pumping wells ranges from 5,000 to 10,000 gallons per day per foot (roughly 670 to 1,340 square feet per day (ft^2/d). Most groundwater flow in bedrock occurs in the upper 500 feet throughout the Newark Basin (Sefres 1994).

1.4.4.2 Site Hydrogeology

The following subsections summarize the site hydrogeology. A detailed analysis of site hydrogeology is included in the final RI report (CH2M 2014a).

Overburden Hydrogeology. The most recent potentiometric surface map, December 2014, is shown in Figure 1-9. As shown in Figure 1-9, groundwater flow in the overburden is consistent with regional groundwater trends flowing from the east toward west within the site. Although the current well network located west of the Passaic River is limited, the December 2014 synoptic water level measurements suggest that groundwater flow in the overburden aquifer in the city of Passaic occurs from west to east, and appears to discharge to the Passaic River. Groundwater flow in the overburden aquifer mirrors the topography and flows toward the Passaic River.

The potentiometric surface elevation observed across the site varies from approximately 3 feet amsl to 50 feet amsl in the overburden. Hydraulic gradients in the overburden, range from 0.0065 foot per foot (ft/ft) to 0.0385 ft/ft, with an average gradient of 0.015 ft/ft across the site from east to west. Upgradient of the ECE property, vertical groundwater flow is downward from the overburden to bedrock, consistent with a recharge zone. However, at the ECE property and downgradient throughout the rest of the site, vertical groundwater flow is observed as upward, from bedrock to the overburden. Vertical gradients were calculated between closely spaced well clusters of overburden and bedrock conventional monitoring wells and for FLUTe wells monitoring discrete bedrock zones. Throughout the site, overburden groundwater head was observed at higher head than in the Passaic River, suggesting potential discharge to the river. Saturated thickness in the overburden near the ECE property ranged from about 5 to 15 feet.

During the 1990s, a hydrogeology study was performed at the former Kamala Chemical property, which is located within the site. Results of the study indicated a hydraulic conductivity ranging from 0.3 to 12 feet per day (ft/d), with an average value of 3.0 ft/d in the shallow overburden (less than or equal to 20 feet bgs). The hydraulic conductivity in the deeper overburden ranged from 0.33 to 0.52 ft/d. During these studies, transmissivity was determined to be 3,500 gallons per day per foot and storativity was 0.001.

Bedrock Hydrogeology. The most recent potentiometric surface map generated during December 2014 is shown in Figure 1-10. As shown in Figure 1-10, groundwater flow in bedrock is consistent with regional groundwater trends flowing from the east toward west within the site. Groundwater flow in the Passaic Formation (Brunswick aquifer) is oriented toward the west, with preferential flow through a discontinuous network of fractures and bedding parting.

The potentiometric surface elevation observed across the site varies from approximately 5 to 45 feet amsl in bedrock. The similarity in water level elevations suggests that the Brunswick aquifer present in bedrock may be unconfined or semiconfined and hydraulically connected to the overburden aquifer. Hydraulic gradients in the bedrock ranged from 0.0054 to 0.25 ft/ft, with an average gradient of 0.014 ft/ft across the site from east to west. Within bedrock, the distribution of vertical heads suggests mixed downward and upward flow regimes until closer to the Passaic River, where potentiometric heads progressively increased with depth, suggesting more consistent upwards flow within the bedrock. All heads within the bedrock were higher than the head in the Passaic River, suggesting potential discharge to the river.

During the RI, hydraulic packer testing and FLUTe hydraulic conductivity profiling (FHCP) was conducted at various depths intervals throughout bedrock. Packer testing resulted in transmissivity values in bedrock ranging from 0.11 to 1,045 ft^2/d, resulting in hydraulic conductivity values ranging from 0 for 52.27 ft/d. FHCP returned transmissivity values ranging from 0.23 to 50.3 ft^2/d and were consistent with the packer testing results for values ranging from 0.1 to 5 ft^2/d. At transmissivity values greater than 5 ft^2/d, the FHCP values were on average 1.95 times smaller than the packer testing results. Details on the hydraulic packer testing and FHCP are in the *Hydraulic Analysis of Packer Testing Technical Memorandum,* Appendix C of the RI report (CH2M 2014a).

In 2007, an additional hydrogeology study focused on bedrock was performed at the former Kamala Chemical property. Results of the study indicated a hydraulic conductivity ranging from 0.005 to 2.5 ft/d, with an average value of 0.56 ft/d in the bedrock (Sovereign Consulting Inc. 2008). In 2013, a site-specific aquifer pump test was conducted at the Grand Street Property, as described in Section 2.2.2. Results of the pump test provided estimates of the hydraulic conductivities within the bedrock ranging between 0.24 and 0.94 ft/d, within the range estimated during the 2007 Kamala Chemical property study (Sovereign Consulting Inc. 2008). Additionally, results show that there was no indication of strong anisotropy or isolated fracture flow during the pump test. Further details on the aquifer test are included in Section 2.2.2 and in Appendix A, *Results of Aquifer Testing, Garfield Groundwater Contamination Superfund Site, New Jersey Technical Memorandum* (CH2M 2014b).

SECTION 2

Remedial Investigation Activities and Conceptual Site Model

Section 2 provides a brief description of historical RIs that have taken place at the ECE property and downgradient plumes since the documented release in 1983. Additionally, a brief summary and conclusions from two post-RI studies, including the Grand Street aquifer pump test and the ECE property in situ reduction pilot test, are included. Following completion of the RI and post-RI studies, the CSM for the ECE property and downgradient plume was updated; and a discussion is included on the current nature and extent of contamination, contaminant fate and transport mechanisms, and risks to human health and the environment from exposure to contaminated media

2.1 Previous Remedial Investigations (1984-2011)

Following the December 1983 spill and subsequent cleanup effort in April 1984, a number of investigations were performed onsite before the site being listed under the Superfund program in 2011. No record of remedial or monitoring activities at the site is available from 1984 to 1992. The following investigations were carried out from 1993 through 2011 by ECE, NJDEP, and USEPA:

- 1993: Cr-contaminated groundwater was discovered in Garfield Fire House #3. ECE entered into a Memorandum of Agreement with NJDEP to comply with regulatory investigation requirements (New Jersey Department of Health and Senior Services [NJDHSS] 2007).
- 1994: ECE installed one overburden groundwater monitoring well 10 feet downgradient of the vertical tank. Total Cr was detected at 288,000 micrograms per liter (µg/L), and Cr(VI) was detected at 260,000 µg/L (Raritan Enviro Sciences, Inc. 1995).
- 1999: ECE installed three bedrock groundwater monitoring wells on the ECE property from 30 to 44 feet bgs (ECE-08-BR, ECE-09-BR, and ECE-10-BR). Total Cr was detected from 11,000 to 1,500,000 µg/L, and Cr(VI) was detected from 5,390 to 1,490,000 µg/L.
- 2000–2001: NJDEP collected samples from sump water and solid residuals from 10 residential basements downgradient of the ECE property. Total Cr was detected in sump water at 6 locations with concentrations ranging from 2 to 12,100 µg/L, and Cr(VI) was detected in sump water at 3 locations with concentrations ranging from 54 to 11,300 µg/L. Total Cr also was detected in residual solids from the sumps at four locations, with concentrations ranging from 5.71 to 18.7 milligrams per kilogram (mg/kg).
- 2002: NJDEP engaged USEPA for removal action consideration based on financial difficulties cited by the property owner and concern over Cr(VI) contamination in groundwater seeping into basements downgradient of the ECE facility.
- 2002-2006: USEPA investigated incidents of Cr contamination and determined several residential basements have impacts. The Agency for Toxic Substances and Disease Registry (ATSDR) and NJDHSS evaluated the potential for exposure and recommended that USEPA delineate the entirety of both the bedrock and overburden plumes.
- 2003: The Garfield Housing Authority collected samples from groundwater and groundwater residue in the basement of the Golden Tower Apartments. Based on analytical results, removal actions for the Cr contamination were performed at the property, under NJDEP guidance.
- 2003: NJDEP collected water samples from the basement of the former Garfield Fire House #3. Analytical results indicated that total Cr was present; Cr(VI) was not analyzed in the samples (NJDHSS 2007).

- 2008: ECE collected soil samples beneath the concrete floor of the ECE facility to the top of bedrock; Cr(VI) concentrations ranged from less than 0.89 to 7,590 mg/kg, exceeding the New Jersey soil remediation standards for residential soil (240 mg/kg) and the NJDEP 2007 Chromium Policy Directive memorandum standard for Cr(VI) in soil (20 mg/kg).
- 2008-2009: USEPA performed a comprehensive study in the community downgradient of the site, including sampling of surface soils, Passaic River sediments, and surface water. Total Cr was detected in surface soils, sediments, Golden Tower Apartment Complex basement water samples, and surface water samples from the eastern bank of the Passaic River. Cr(VI) was only detected in water samples from the basement of the apartment complex (CH2M 2014a).
- 2010: USEPA collected groundwater samples to fully delineate the Cr(VI) groundwater overburden and bedrock plumes. Cr(VI) was detected at 11 of 39 locations sampled at concentrations greater than the New Jersey groundwater quality standard (GWQS), for total Cr of 70 µg/L. The total Cr NJDEP GWQS was used since no NJDEP GWQS exist for Cr(VI), and the total Cr concentrations at the site are predominately in the Cr(VI) form. Soil samples collected during the investigation throughout the study area returned a maximum Cr(VI) concentration of 22.6 mg/kg, which exceeds the NJDEP 2007 Chromium Policy Directive memorandum standard for hexavalent chromium in soil of 20 mg/kg.

Further detail regarding previous site investigations are in the final RI report (CH2M 2014a).

2.2 Remedial Investigation, Aquifer Testing and Pilot Study Activities

2.2.1 USEPA Remedial Investigation (2011–2013)

On September 16, 2011, the ECE property was officially listed on the NPL (USEPA ID NJN000206317), as the Garfield Groundwater Contamination Superfund Site. Following listing as a Superfund site, USEPA conducted additional sampling and completed an RI between 2011 and 2013. The RI was carried out in four separate phases and included sampling groundwater in overburden and bedrock both on- and offsite, packer testing, groundwater-surface water interaction evaluation, production well discrete depth groundwater sampling, surface sediment sampling, and residential soil sampling. In addition, bedrock cores were collected during the RI to characterize site geology and porewater geochemistry and a matrix diffusion study to evaluate the potential presence and possible concentrations of Cr(VI) diffused in the underlying bedrock matrix.

Results of the RI were used to support developing a CSM and complete a screening-level ecological risk assessment (SLERA), Step 3A baseline ecological risk assessment (Step 3A baseline ecological risk assessment [BERA]), and a human health risk assessment (HHRA), as discussed in Section 2.3.3. Further details regarding the USEPA RI are in the final RI report (CH2M 2014a).

2.2.2 Grand Street Aquifer Testing (2013)

An aquifer test was carried out in late 2013 to provide site-specific characterization of hydraulic conditions in an area of the site where higher concentrations of Cr(VI) were detected during the RI. The aquifer test was performed downgradient of the ECE property near the intersection of Grand Street and Cambridge Avenue (Figure 2-1). Six monitoring wells were installed to facilitate the aquifer test: two in the overburden, two in the shallow bedrock, and two in the intermediate bedrock. Existing well EPA-21-BR was selected as the pumping well for the aquifer test. The pumping interval for the aquifer test was from the bottom of the isolation casing (68 feet bgs) to the top of the packer (140 feet bgs), representing a 72-foot interval.

Hydrostatic pressure transducers were installed in the six monitoring wells, plus one background well, and above and below the packer in the pumping well. For 2 weeks prior to starting the aquifer test, ambient water level data were collected. A two-step drawdown test, at pumping rates of 2 gpm for

1 hour and 5 gpm for 2 hours, was carried out before the aquifer test. Based on the drawdown test, the constant rate aquifer test, carried out over 24 hours, was set at a pumping rate or 3.5 gpm for 10 hours, and then 4.1 gpm for the remainder of the test. Drawdown in the pumping well at the end of the test was about 50 feet. Drawdown of 2 to 3 feet was also observed in both the shallow and intermediate bedrock wells, but was not apparent in the overburden wells.

Results of the aquifer test were used to provide estimates of hydraulic parameters for the site, using a multilayer unsteady state (MLU) software package. Results of the MLU modeling were used to estimate hydraulic conductivity values in bedrock, which were estimated to range between 0.24 and 0.94 ft/d. Additionally, results show that there was no indication of strong anisotropy or isolated fracture flow during the pump test.

The results of the aquifer testing were used to support further modeling of solute transport mechanisms, as detailed in Sections 2.3.2 and 7.4.1, and support development of alternatives in this FS. Further details on the aquifer test are in Appendix A, *Results of Aquifer Testing, Garfield Groundwater Contamination Superfund Site, New Jersey Technical Memorandum* (CH2M 2014b).

2.2.3 ECE Property In Situ Reduction Pilot Test (2014)

An in situ reduction pilot study was carried out at the ECE property in 2014 to gain additional information in support of this FS. The objectives of the pilot study were to investigate the practicability of injecting reagents into the overburden with direct-push technology, achievable reduction of Cr(VI) mass in the overburden groundwater, and the practicability of creating reducing zone barriers as part of a full-scale remedy.

Before initiating injections, four overburden groundwater monitoring wells were installed on the ECE property to facilitate performance monitoring during the pilot study. Three wells were installed upgradient, downgradient, and within the injection barrier zone, and one well was installed within the source area treatment zone. Groundwater samples were collected from the newly installed wells to document preinjection baseline conditions.

A one-time injection of emulsified vegetable oil (EVO) and magnesium sulfate was carried out at 40 locations in the overburden on the ECE property, using direct-push technology. Twelve injection points were installed in the source area over a 35-foot by 50-foot area, and 28 injection points were installed to create a 120-foot-wide reductive barrier on the downgradient side of the site (Figure 2-2). A total of 3,448 gallons of 60 percent EVO product, 1,374 pounds of magnesium sulfate, and 25,254 gallons of potable water was injected during the pilot study from a depths of 13 to 28 feet bgs, between the water table and top of bedrock. Injections were carried out at an average pressure of 15.3 pounds per square inch and an average flow rate of 2.8 gpm.

The direct-push equipment hit refusal at several injection locations during the injection process at depths ranging from 11 to 28 feet bgs. Because of refusal, several injection points received less than designed amounts of EVO at intervals that differed from the design. Additional injection locations were advanced either as step outs from locations with shallow refusal or as new locations to increase the total EVO distributed to the subsurface. The heterogeneity in the overburden resulted in non-uniform distribution of injection solutions laterally across the site.

Following the injection work, five rounds of performance monitoring were carried out over a 7-month period. Results of the performance monitoring indicated that in situ reduction has the potential to be successfully implemented to remediate Cr(VI) outside the source area. Cr(VI) concentrations downgradient of the injection barrier decreased by more than 97 percent following the injections, from 18,400 µg/L to 9 µg/L at EPA-13-OB and from 125,000 µg/L to 2,880 µg/L at EPA-30-OB. The main mechanism for contaminant concentration reduction was likely biogeochemical reduction of Cr(VI) to trivalent chromium [Cr(III)]. In the source area, which had low pH (as low as 3.13 in EPA-29-OB) and elevated concentrations of Cr(VI) inhibitory to microbial growth, Cr(VI) levels remained elevated following the pilot injection.

If implemented as a full-scale remedy, it is recommended that permanent injection wells be used and total injection volume be increased to achieve greater injection uniformity and radius of influence. Because of low pH and high concentrations of Cr(VI) within the source area, biological reduction by itself is not expected to be effective within the source area. Source zone reduction could be implemented through chemical reduction, a combination of chemical and biological reduction and/or pH buffering. Results of the pH titration tests indicate that to neutralize the soil within the ECE property, sodium hydroxide, or a similar base, would need to be added at a dose of 0.0161 millimol per gram of dry soil, or approximately 2 pounds of sodium hydroxide per cubic yard of soil. Within the overburden plume, an increase in the EVO dosage is recommended to maximize the longevity of the reduction zones and to provide contingency against non-uniform EVO distribution. Further details on the pilot test results are found in Appendix A, *Results of the In Situ Reduction Pilot Study, Garfield Groundwater Contamination Superfund Site, New Jersey Technical Memorandum* (CH2M 2015a).

2.3 Conceptual Site Model

The CSM for the ECE property and downgradient groundwater plumes was developed following completion of the RI and the aquifer and pilot tests. The CSM compiles and integrates information about nature and extent of contamination, contaminant fate and transport mechanisms, and risks to human health and the environment from exposure to contaminated media. The CSM is used to support the evaluation of potential effectiveness of remedial alternatives in Section 7.

2.3.1 Nature and Extent of Contamination

The horizontal and vertical distribution and extent of Cr contamination was established during the RI, and updated with soil data from the 2013 source area investigation and removal actions and groundwater data from the 2014 sampling events. Since the total Cr nature and extent is closely represented by the Cr(VI) nature and extent, the nature and extent discussion will focus on Cr(VI). Figure 2-3 is included as a reference of the comprehensive well network that exists onsite.

2.3.1.1 Source Area

The ECE property is considered the source area for the site because of documented, and possible undocumented, historical releases of chromic acid associated with onsite plating processes. According to the spill report from 1983, approximately 5,560 pounds of Cr(VI) were released into the subsurface environment at the source area. It is possible that other, undocumented releases also occurred at the facility prior to this date.

Results of the 2013 source area investigation found Cr(VI)-impacted soil above the NJDEP 2007 Chromium Policy Directive memorandum standard for Cr(VI) in soil (20 mg/kg) across the majority of the ECE property at depths ranging from 0 to 16 feet bgs, as shown in Figure 4 of the *Removal Assessment Sampling Trip Report EC Electroplating* (Weston Solutions, Inc. 2013), which is included in Appendix B. A maximum soil concentration of 1,660 mg/kg was detected from 10 to 12 feet bgs near the historical location of the chromic acid tank (Weston Solutions, Inc. 2013). Based on the results of the source soil sampling event, a revised estimate of the total mass of Cr(VI) in the source area overburden soils alone is more than twice the amount reportedly released during the 1983 spill. The mass balance calculation supports that unreported spills, leaks, or other sources of contamination may have occurred historically at the former ECE property.

Cr(VI) concentrations in overburden groundwater at the source area were detected during the most recent sampling event (December 2014) at a maximum concentration of 269,000 µg/L, at EPA-32-OB, near the historical location of the chromic acid tank (Figure 2-4). Cr(VI) concentrations, across the ECE property, are more than three orders of magnitude greater than the NJDEP GWQS for total Cr of

70 µg/L. The total Cr NJDEP GWQS is used since no NJDEP GWQS exist for Cr(VI) and the total Cr concentrations at the site are predominately in the Cr(VI) form. Additionally, as a result of the chromic acid spill, pH in groundwater within the source area is low (3.28) near the spill location (EPA-29-OB), compared with upgradient pH of 6.44 (EPA-14-OB) and downgradient pH of 7.53 (EPA-13-OB), during the most recent sampling event (December 2014).

Cr(VI) concentrations in bedrock groundwater at the source area have been detected at a maximum concentration of 86,500 µg/L, at ECE-10-BR in 2011 (Figure 2-3). Cr(VI) concentrations, at other locations across the ECE property (ECE-08-BR and ECE-09-BR) ranged from 1,760 to 2,120 µg/L, less than two orders of magnitude greater than the NJDEP GWQS for total Cr of 70 µg/L. During the RI, a former industrial well, installed in 1966 and located within the ECE facility, was sampled using packers to a depth of 566 feet bgs. Analytical results from this location were below the NJDEP GWQS for total Cr at all depths (CH2M 2014a). During the 2014 soil removal actions on the ECE Property (Section 3.3), the three bedrock monitoring wells (ECE-08-BR, ECE-09-BR, and ECE-10-BR) were abandoned in place.

2.3.1.2 Overburden Groundwater Plume

The extent of the overburden groundwater Cr(VI) plume expands westward from the source area at the ECE property to the leading edge at the Passaic River, as evident by non-detect concentrations of Cr(VI) in wells located across the Passaic River (Figure 2-4). The approximate boundaries of the Cr(VI) plume, defined as concentrations exceeding the New Jersey GWQS, for total Cr of 70 µg/L, encompass a north-south width of 1,730 feet (from the area near Van Winkle Avenue to Commerce Street) and a length of more than 3,000 feet from the east (ECE property) to the west (Passaic River). The Cr(VI) plume extends through the full saturated thickness of the overburden, which ranges from approximately 10 to 50 feet. Cr(VI) concentrations decrease along the axis of the overburden plume from a high on the ECE property to low near the Passaic River. The maximum concentration of Cr(VI) detected in the overburden plume during the December 2014 sampling event, not including wells located on the ECE property, was 14,900 µg/L at well EPA-06-OB, near the center of the plume. By comparison, the concentration in downgradient well EPA-04-OB, located near the Passaic River, was 1,690 µg/L.

2.3.1.3 Bedrock Groundwater Plume

The Cr(VI) concentrations in bedrock groundwater, as shown in Figure 2-5, indicate that the plume expands westward from the source area at the ECE property, beneath the Passaic River, and into the boundaries of the city of Passaic. The approximate boundaries of the Cr(VI) plume, defined as concentrations exceeding the New Jersey GWQS, for total Cr of 70 µg/L, encompass a north-south width of approximately 1,800 feet (from Van Winkle Avenue in the north past Hudson Street in the south) and a length of more than 3,000 feet from the east (ECE property) to the west (into the city of Passaic). Cr(VI) has been detected to depths of up to 350 feet bgs within the Passaic Formation. Cr(VI) concentrations decrease within the bedrock aquifer from the source area to across the Passaic River and with increasing depth in the bedrock aquifer. The maximum concentration of Cr(VI) detected in the bedrock plume during the December 2014 sampling event was 26,800 µg/L at a depth of 58 to 68 feet bgs in EPA-16-BR, near the center of the plume. By comparison, Cr(VI) was detected west of the Passaic at a maximum concentration of 269 µg/L at a depth of 118 to 128 feet bgs in EPA-19-BR.

2.3.2 Fate and Transport of Chromium in the Environment

The fate and transport of Cr from the source area to the overburden and bedrock plumes were characterized based on the findings from the RI. The findings were used to profile the mobility and persistence of Cr(VI) in both the overburden and bedrock aquifers. Additionally, the findings were used to create a groundwater flow model and Cr(VI) transport model for the site. The fate and transport of Cr(VI) in groundwater, as well as modeling results, are summarized below.

2.3.2.1 Source Area

Cr plating solutions (for plating baths), like that released in the source area, typically consist of a mixture of chromic acid ($H_2Cr_2O_7$) and sulfuric acid (H_2SO_4), are highly acidic (pH=0) and have a density greater than the native groundwater (specific gravity of approximately 1.1 based on dosing of 46 oz. per 1 gallon) (Chapin Engineering 2009).

Within the source area, there is a natural upward hydraulic gradient into the overburden aquifer from the bedrock aquifer. Upgradient of the ECE property, at EPA-14-OB/BR, groundwater flowed vertically downward from the overburden to the bedrock consistent with a recharge zone, during the RI. Throughout the rest of the site, such as at EPA-13-OB/BR and EPA-16-OB/BR, groundwater flow is upward from the bedrock to the overburden. No well pairs exist within the limits of the source area; however, EPA-13-OB/BR is just downgradient from the site, indicating that the groundwater gradient onsite is most likely upward on the ECE property as well. Despite the natural upward hydraulic gradient onsite, contaminant transport across the source area is driven by a density-driven flow, in which the high total dissolved solids (TDS) mixture of groundwater and plating solution migrates through the overburden aquifer to enter the deeper bedrock aquifer as it traveled downgradient away from the source area.

As observed during the pilot study, the acidic nature of the plating solution has lowered the pH in groundwater within the source area to below 5. As groundwater migrates through the overburden and shallow bedrock, the pH is rapidly neutralized by reaction with calcite and by mixing with the native circum-neutral pH and moderately bicarbonate-rich groundwater. Additionally, the highly oxidizing nature of the solution would have rapidly exhausted any potential for native organic matter or other reducing phase in the affected materials to convert Cr(VI) to immobile Cr(III). This is evident because of the high oxidation-reduction potential (ORP) values observed in the overburden wells onsite during the baseline sampling of the pilot study (June 2014), ranging from a high of 530 millivolts (mV) at EPA-29-OB (source area) to 103 mV at EPA-30-OB (downgradient), and low total organic carbon (less than 3 milligrams per liter [mg/L]).

2.3.2.2 Overburden Plume

Cr(VI)-impacted groundwater migrates through the overburden aquifer, which is composed of mixtures of unconsolidated gravel, sand, and silt overlying weathered bedrock. Groundwater flow and solute transport in the overburden appears consistent with equivalent porous media.

The geochemistry in the overburden aquifer indicates that groundwater is moderately oxidizing on average, but likely contains microzones that are slightly reducing. The oxidizing conditions are defined by the measured positive ORP readings between 0 and +200 mV during the December 2014 sampling event. During the December 2014 sampling event, dissolved oxygen (DO) concentrations were moderate throughout much of the aquifer, ranging from 0 mg/L to 7 mg/L, with an average of 3.1 mg/L, further indicating positive redox conditions. Additionally, nitrate is present in the aquifer (between 2 and 7 mg/L) and iron and manganese are detected at very low concentrations (less than 2 mg/L). Taken together, the ORP measurements, the moderate levels of DO concentrations, the presence of nitrate in many samples, and the absence of detectable concentrations of dissolved iron and manganese in many samples suggest that the overburden aquifer is moderately oxidizing on average.

The oxidizing nature of the overburden aquifer supports the conclusion that the majority of the measured Cr in groundwater exists as Cr(VI). Additional total Cr and Cr(VI) data collected during the December 2014 sampling event, indicate that on average the Cr(VI) concentrations are greater than 75 percent of the concentration of the total Cr. In contrast, Cr(III) concentrations on average are less than 15 percent of the total Cr concentration.

Small micro-zones that are slightly reducing have also been detected in the overburden aquifer. The main area where reducing conditions were observed during the December 2014 sampling event was near EPA-

10-OB and EPA-13-OB. The reducing microzones are identified by low ORP values (-100 to -200 mV) and low to nondetect DO concentrations (less than 0.5 mg/L). The reducing conditions observed during the December 2014 sampling event near EPA-10-OB are consistent with historical ORP and DO values. The reducing conditions observed at EPA-13-OB are most likely a result of the source area in situ pilot study.

TDS concentrations along the center axis of the overburden plume range between 400 to 500 milligrams per liter (mg/L), and the calcium and biocarbonate concentrations are higher than in the background groundwater. The waters in the overburden aquifer are slightly acidic to circum-neutral, with pH increasing with distance downgradient from the source. pH values ranged from 3.25 on the ECE property to 8.57 in the downgradient plume in 2014. Consistent with this trend, geochemical modeling indicates the background water is undersaturated with respect to calcite, whereas the plume water is saturated or oversaturated with respect to calcite.

The Cr(VI) concentrations decrease along the central axis of the overburden plume, with maximum concentrations detected in the source area, and lower concentrations detected near the Passaic River.

2.3.2.3 Bedrock Plume

Cr(VI)-impacted groundwater migrates through the bedrock aquifer mainly through secondary porosity features, defined by a system of stacked, leaky-confined aquifer systems connected by through-going vertical fractures (Michalski 1990). The bedrock is composed of sandstones, siltstones, and shale and exhibits little primary porosity. In addition to the individual fractured zones, three sandstone beds influence the location of the fracture networks at depths between 80 and greater than 200 feet bgs. These sandstone beds exhibited greater average hydraulic conductivities than other zones in finer-grained rocks. However, no dominant groundwater flow paths have been identified in the bedrock aquifer, and flow is likely to be heterogeneous and tortuous from the ECE property to downgradient.

The pH of the bedrock groundwater is neutral to alkaline, ranging between 7 and 10 in shallow to intermediate depths, and 9 to 13 at depths greater than 200 feet bgs, during the December 2014 sampling event. This is groundwater that flows through the fractured network and may not represent the porewater in the rock matrix. The geochemistry in the shallow bedrock aquifer indicates that groundwater is moderately oxidizing and similar in geochemical makeup to that of the overburden. ORP values are moderately positive ranging between 0 to +200 mV, with some negative ORP detected in pockets throughout the aquifer near EPA-16-BR, EPA-18-BR, EPA-19-BR, and EPA-22-BR and at depths greater than 300 feet bgs. DO and nitrate concentrations are similar to those in the overburden, and iron and manganese concentrations are very low (less than 0.2 mg/L).

The oxidizing nature of the bedrock aquifer supports the conclusion that the majority of the Cr in the groundwater exists as Cr(VI). Additional total Cr and Cr(VI) data collected during sampling events indicates that on average the Cr(VI) concentrations are greater than 85 percent of the concentration of the total Cr. In contrast Cr(III) concentrations on average are less than 20 percent of the total Cr concentration.

TDS concentrations in the bedrock aquifer decrease with depth, with concentrations in the shallow bedrock similar to those in the overburden, and those in the deeper bedrock being significantly lower. The shallow bedrock groundwater are dominantly calcium-chloride type waters with significant concentrations of magnesium and bicarbonate. This chemistry is consistent with a mixture of the calcium-chloride-dominated groundwater from the overburden aquifer and a magnesium-bicarbonate-dominated water from the intermediate bedrock zone. Deep bedrock groundwater consist of sodium sulfate and sodium bicarbonate waters.

The Cr(VI) concentrations decrease along the central axis of the bedrock plume, with maximum concentrations detected below the source area, and lower concentrations detected near the Passaic River. The oxidizing nature and relatively high pH of the groundwater, limits abiotic reduction, microbial reduction, or sorption of the Cr(VI). Hexavalent chromium migrates to depths exceeding 300 feet bgs;

however, the highest concentrations were found at depths ranging from 60 to 130 feet bgs. Concentrations at deeper depths (greater than 200 feet bgs) fall below method detection limits as the plume approaches the Passaic River.

The University of Guelph performed a matrix diffusion study in 2012 (University of Guelph 2013) to evaluate the distribution of Cr(VI) in the rock matrix versus groundwater in fractures to assess whether matrix diffusion is an important process affecting Cr(VI) fate and transport. A total of 100 rock core samples from EPA-21-BR over a depth interval of 69 to 355.5 feet bgs were analyzed for Cr(VI) concentrations in the rock matrix. The resulting porewater concentrations were compared to groundwater concentrations from sampling of FLUTe ports at EPA-21-BR. Overall results of the study suggest that significant matrix diffusion has occurred in the shallower intervals (down to 117 feet bgs) given that the porewater concentrations were as high or higher than the groundwater concentrations measured in FLUTe ports. These are also the depths with the highest groundwater concentrations. Deeper depths had less Cr(VI) in the rock matrix porewater, but also lower concentrations in the groundwater.

2.3.2.4 Groundwater Three Dimensional Visualization Modeling

Results from the RI groundwater sampling, and subsequent sampling events through 2014, were entered into the 3D visualization software program MVS developed by C-Tech. The software uses analytical laboratory results to create a 3D image of the extent of Cr(VI) contamination in the overburden and bedrock aquifers. 3D images are presented in this report to help visually convey the spatial distribution and concentrations of the Cr(VI) plumes in groundwater at concentrations exceeding the New Jersey GWQS for total Cr (70 µg/L) in both the bedrock and the overburden. Figures 2-6 through 2-8 present images of the 3D graphics from three perspectives across the site.

The MVS software was also used to estimate the total volume of the Cr(VI) plumes in groundwater. The boundaries of the bedrock and overburden plumes were defined as the New Jersey GWQS for total Cr. An overburden porosity value of 0.35 (35 percent) was used in the MVS software, as was determined during the RI. The matrix porosity value for bedrock, 0.10 (10 percent), was used in the MVS software, as was obtained from the results of the matrix diffusion study (University of Guelph 2013).

The software was also used to develop an estimate of the volumetric size of the plumes in the overburden and bedrock aquifers. The estimated volume of groundwater with concentrations above the New Jersey GWQS for total Cr beneath the site was calculated from the 2012 first sampling event and updated using the 2014 groundwater data. Results of the 2014 MVS output indicate the total volume of impacted groundwater is 815 million gallons. Approximately 46 percent (378 million gallons) of the contaminated groundwater is located within the overburden aquifer, and 54 percent (436 million gallons) of the volume is within the bedrock aquifer.

2.3.2.5 Groundwater Flow and Chromium Transport Modeling

A numerical model of the site was built using the groundwater flow and solute transport modeling software MODFLOW-SURFACT (HydroGeoLogic 2008). The numerical model was carried out in two phases, building and calibrating the groundwater flow model (Phase I) and building a contaminant transport model that used flow data from the Phase I model (Phase II).

The Phase I model was set up as five separate stratigraphic layers over an area of 3.3 square miles, with 50-foot grid spacing. General head boundary conditions were set up on the east and west boundaries of the plume, with the Passaic River as the boundary condition in the overburden layer. The Phase II model used the flow model framework to conduct dual-domain transport simulations, with a mobile domain modeled by well-connected pores or fractures and contaminant transport dominated by advection, and an immobile domain modeled by poorly connected pores (such as rock matrix) and contaminant transport dominated by diffusion. Contaminant exchange between the two domains takes place solely via diffusion.

The numerical model was used to develop remedial alternatives and estimate clean up timeframes for remedial alternatives as described in Section 7.4.1. Details of the numerical model can be found in the *Garfield Groundwater Contamination Superfund Site Phase 1 Groundwater Flow Modeling Technical Memorandum* (CH2M 2014c) and the *Garfield Groundwater Contamination Superfund Site Phase 2 Solute Transport Modeling Technical Memorandum* (CH2M 2015b) included in Appendix C. As discussed in more detail in Section 7.4.1 and Appendix C, the cleanup timeframe predictions are sensitive to parameters that must be estimated based on assumptions of the plume history. As such, there is a high level of uncertainty in these predictions.

2.3.3 Summary of Ecological and Human Health Risk Assessment

An HHRA was conducted for the site to evaluate the potential health risks from future exposures to groundwater, assuming groundwater could be used as a source of drinking water in the future. The results of the HHRA identified seven contaminants of potential concern (antimony, barium, total Cr, copper, Cr(VI), nickel, and vanadium) in groundwater exceeding the adjusted tap water regional screening level (RSL). Potential risks were estimated for a future residential drinking water scenario using conservative assumptions for exposure factors and exposure point concentrations. The maximum target organ or critical effect-specific hazard index (HI) estimates for no observed effect in adults was 141 and 355 in children, due to hexavalent and total Cr. The estimated excessive lifetime cancer risk for Cr(VI) exceeds USEPA's acceptable risk range of 1×10^{-6} to 1×10^{-4}. The estimated critical effect HI for Cr(VI) and total Cr exceeded 1. Therefore, these two chemicals were identified as contaminants of concern (COCs) for site groundwater under a future potable use scenario.

A SLERA and Step 3a BERA were conducted as part of the RI (CH2M 2014a) to evaluate the potential for risk to ecological receptors from contamination in the absence of any remedial action. Potential complete exposure pathways for ecological receptors included areas where groundwater discharges to the Passaic River. Potential ecological receptors using the Passaic River include benthic macroinvertebrates, water column-dwelling aquatic life, mammals, and fish-eating birds. The potential ecological risk to these receptors from exposure to surface water and sediment along the Passaic River was evaluated in the SLERA and Step 3A BERA. The following summarizes the findings and conclusions for each receptor group following completion of the Step 3A BERA:

- The Step 3A BERA indicated a potential for adverse effects to benthic macroinvertebrates from the presence of Cr in surface sediment at the location of groundwater discharge. The later BERA conducted in 2014 demonstrated no significant ecological risk to the benthic invertebrate community.
- Cr concentrations in surface water do not represent a potential risk to aquatic life and this receptor/exposure pathway does not warrant further evaluation.
- There is negligible potential for Cr in sediment and surface water to represent a risk to mammalian and avian wildlife.

The SLERA indicated a potential for adverse effects to wildlife from the ingestion of Cr in food items. Although appropriate for the SLERA evaluation, the highly conservative assumptions used in the SLERA (for example, 100 percent of food derived from the site, and 100 percent bioavailability of Cr for accumulation and uptake) will overestimate actual risk. The refined food web models used in the Step 3A BERA incorporate less conservative (but more realistic) assumptions and additional methods relative to those used in the SLERA. The Step 3A BERA indicated a negligible potential for Cr in sediment and surface water to represent a risk to mammalian and avian wildlife.

In 2014, in order to further define the potential risk to the community of benthic organisms in the Passaic River, a BERA was completed. The BERA evaluated the potential exposure and consequent risk of Cr contamination to the benthic organisms inhabiting the eastern side of the river bottom in the city of Garfield. Based on a 42-day Hyalella azteca survival, growth, and reproduction sediment toxicity test, Cr levels in sediments located along the eastern side of the Passaic River between Faber Place and Monroe Street pose no ecological significant risk to survival and reproduction in the benthic invertebrate community inhabiting the area (Avatar Environmental 2015). Based on the results of the BERA, groundwater impacted with Cr(VI) from the ECE property discharging to the Passaic River poses no threat to the benthic community.

SECTION 3

Removal Actions

3.1 Summary of Basement Removal Actions

In October 2002, NJDEP referred the ECE property to USEPA for removal action consideration because of the concern that groundwater contaminated with Cr(VI) was seeping into the basements of buildings located downgradient of the ECE property. The Cr(VI) entered the basements with groundwater during rain events and crystallized on the walls and floors of some of the basements, thereby creating the potential for residents who may be active in the basements to be exposed to Cr(VI) via ingestion and inhalation.

Between 2002 and 2006, USEPA investigated incidents of Cr(VI) contamination within buildings near the ECE property and discovered several basements that had been affected. In September 2006, USEPA requested that ATSDR evaluate the potential for exposure to contaminated groundwater. In response, ATSDR and NJDHSS recommended that USEPA delineate the contaminated overburden groundwater plume and investigate groundwater seepage into basements (USEPA 2014a).

USEPA initiated a comprehensive study in the community downgradient of the site in fall 2008, including visual inspections and sampling of both groundwater and residue in basements. From 2008 through 2013, USEPA identified 710 properties that fall within the boundaries of the overburden groundwater plume, and may be potentially impacted by contaminated groundwater, as shown on Figure 3-1. Through 2013, USEPA was granted access to 512 of the properties and performed visual inspections. Based on the results of the visual inspections, samples were collected at 324 of the properties.

During the basement investigations, 1,584 samples were collected for Cr(VI) from the 324 properties that were sampled. Of the 1,584 samples collected, 1,391 were wipe samples (floor, wall, and sump), 95 were collected from the either the sump or standing water in the basement, 84 were collected from sediments in the basement (floor and sump), and 14 were collected from soils. Additionally, air samples were collected at 21 properties with measurable concentrations of Cr(VI) dust.

The initial sampling indicated that removal actions were necessary at 14 properties, based on exceedances of the removal action level (RAL) (USEPA 2010a), location of the property over the overburden groundwater plume, and confirmation of groundwater infiltration in the basement. Maximum Cr(VI) concentrations were detected at properties 229 (44,200 micrograms [µg] per wipe) and 183 (7,090 µg/wipe), both of which are within 500 feet downgradient of the ECE property. Removal actions included installing drainage trenches and sumps at seven properties, decontamination via cleaning at two properties, cleaning and applying a waterproof sealant at three properties, and a combination of sump/drains and applying sealant at two properties. Newly installed drainage trenches and sumps are discharged to the City of Garfield sanitary sewer system.

Levels of Cr(VI) in air were orders of magnitude below the USEPA RSL of 1.1E-05 micrograms per cubic meter ($\mu g/m^3$) (USEPA 2012b). Therefore, the inhalation pathway was not considered to be a pathway of concern. The results of the basement removal actions are detailed in the *EPA Removal Actions – Descriptions of Removal Activities at Residential and Commercial Properties Technical Memorandum* (USEPA 2014a), which is included, along with a summary of sampling results, in Appendix B.

3.2 ECE Property Hazardous Materials Removal and Infrastructure Demolition

ECE ceased all operations in March 2009, and in June 2011, USEPA initiated a site assessment of the abandoned facility. The assessment identified hazardous materials that presented an immediate threat to the surrounding community stored at the property in vats, tanks, and drums. Based on verbal authorization on July 21, 2011, removal actions were performed, which included the inventory, categorization, sampling, analysis, and stabilization of hazardous material at the property. In January 2012, the materials were removed from the property for offsite disposal as hazardous materials.

In July 2012, building materials within the facility were found to contain elevated levels of Cr(VI) and total Cr. In October 2012, the facility was demolished, leaving behind two basements and a concrete slab footprint where the building previously stood (Weston Solutions Inc. 2014).

3.3 ECE Soil Removal Actions

Following the ECE property hazardous materials removal and infrastructure demolition, two basements and a concrete slab footprint where the building stood was all the infrastructure that remained onsite. In April 2013, USEPA’s removal action branch (RAB) conducted a soil sampling investigation to delineate the vertical and horizontal distribution of Cr(VI) in overburden soil on the ECE property. A total of 41 soil borings was advanced on an estimated grid spacing of 30 feet to depths ranging from 7.8 to 18.5 feet bgs. A total of 216 soil samples were collected for Cr(VI) from 2-foot intervals during the soil sampling investigation (Weston Solutions Inc. 2013).

Results of the soil sampling indicated that Cr(VI) was present at concentrations exceeding RAL (20 mg/kg) (NJDEP 2007b) at all depths near the historical location of the process/plating areas of the facility, and at shallow and deeper intervals near the capillary zone in other areas of the site (Appendix B, *Removal Assessment Sampling Trip Report EC Electroplating* [Weston 2013], Figure 4). Additionally, a building material sampling event in June 2012 revealed the concrete slab that remained onsite had Cr(VI) concentrations that exceeded the site-specific cleanup concentration. Results of the soil investigation were used to define the scope of work for the soil removal actions, which included excavating soil within the ECE property boundary that exceeded the soil Cr RAL of 20 mg/kg (Appendix B, *Removal Assessment Sampling Trip Report EC Electroplating* [Weston 2013], Figure 5).

Removal activities were performed at the ECE property between October 2013 and May 2014. During removal actions, Cr(VI)-impacted soils, portions of concrete basements and slab, onsite vats/tanks (cleaned during Phase I), and other debris were excavated and removed from the ECE property. Based on the relative location to the adjacent property, approximately 20 feet of the south wall and a portion of the floor in the south basement were left in place. The vertical extent of the excavation was limited to the unsaturated zone, and no excavations were planned or completed below the water table. The horizontal extent of the excavations were restricted to within the property boundaries of the ECE facility.

Soil removal from the ECE property consisted of 2,986 tons of nonhazardous soil and 2,701 tons of Resource Conservation and Recovery Act (RCRA)-regulated D007 hazardous soil. Soil removed as hazardous waste was taken from locations near tanks and process areas, from the north and south basement areas, and the area between the two basements. During soil excavation, samples were collected from each excavation at every 30 linear feet of sidewall and one per 900 square feet of excavation base. If post-excavation sample results in an excavated area were below the RAL, the excavation was considered complete and subsequently backfilled. Excavation confirmation sample results, to determine if an excavated area was below the RAL, are shown in Figure 3-2. If post-excavation sample results exceeded the RAL, additional excavation was performed until either sampling results were below the RAL or the excavation was approaching the anticipated groundwater table depth. Sample results shown in Figure 3-3 are the final confirmation samples from material left in place at the limits of the excavation.

Concrete removal from the ECE property consisted of 283 tons of nonhazardous concrete and 897 tons of RCRA-regulated D007 hazardous concrete. Concrete removed as D007 waste included the concrete slab over the north basement, the area between the north and south basement, and the concrete wall and floors of the basements. Hazardous concrete was removed offsite for encapsulation and disposal by

Clean Earth of New Jersey. Other concrete was disposed of as construction and demolition waste at the Cumberland Country Landfill. A portion of the floor in the south basement and approximately 20 feet of the south wall were left in place during the soil removal activities, as shown in Figure 3-3, based on the relative location to the adjacent property.

During the excavation activities, wastewater was generated from precipitation events, decontamination of equipment, infiltration of groundwater into excavated areas, and floodwater from the south basement. Wastewater was pumped and stored onsite in a 20,000-gallon frac tank. A total of 19,180 gallons of wastewater was generated during removal actions. The wastewater was disposed of as a RCRA-regulated D007 hazardous waste at the Republic Environmental Systems facility in Hatfield, Pennsylvania.

Two previously undocumented underground storage tanks (USTs) were uncovered during the excavation activities; their locations are shown in Figure 3-3. The tanks were removed, and no evidence of leakage, including soil staining or holes in the tank, was observed. The first tank contained 785 gallons of combustible liquid that was removed into 55-gallon drums and disposed of at Nortle, LLC, in Cohoes, New York. The second tank contained approximately 825 gallons of an oily sludge and solids that were removed into 55-gallon drums and disposed of at Environmental Recovery Corporation of Pennsylvania in Lancaster, Pennsylvania.

Following the completion of removal activities, the excavated areas were backfilled with certified clean backfill (screen dust #10), provided by Maddox Materials, LLC. The material was obtained from the Fanwood Quarry located in Somerset County, New Jersey. A total of 7,529 tons of backfill was placed in excavated areas. Additionally, 114 tons of stone was used for road restoration onsite. Following placement of backfill, the site was restored by placing an impermeable asphalt cap to prevent infiltration of groundwater and reroute stormwater off the site. During site restoration, bin blocks were used to provide additional support to deteriorating cinderblock retaining walls. Removal action was completed on May 15, 2014. Details of the removal actions are included in the *Final Removal Action Report* (Weston Solutions, Inc. 2016), which is included in Appendix B.

SECTION 4

Development and Application of Remediation Goals

4.1 Potential Applicable or Relevant and Appropriate Requirements

As required by Section 121(d) of CERCLA, remedial actions carried out under Section 104 or secured under Section 106 must attain the levels or standards of control for hazardous substances, pollutants, or contaminants specified by the ARARs of federal and state environmental laws and state facility-siting laws unless waivers are obtained, to the extent practicable. According to USEPA guidance, remedial actions should also be based on non-promulgated to-be-considered (TBC) criteria or guidelines if the ARARs do not address a particular situation. Laws and regulations that were evaluated and determined to not be applicable or relevant and appropriate to remedial alternatives developed for the site and this FS are not described herein.

ARARs are identified by USEPA as either being applicable to a situation or relevant and appropriate to it. The degree to which these environmental laws and facility siting requirements must be met varies, depending on the applicability of the requirements described as follows:

- "Applicable" requirements are standards and other environmental protection requirements of federal or state law dealing with a hazardous substance, pollutant, contaminant, action being taken, location, or other circumstance at a CERCLA site. Only those state standards that are more stringent than federal requirements may be applicable. Applicable requirements must be met to the full extent required by law.
- "Relevant and appropriate" requirements are standards and environmental protection criteria of federal or state law that, although not "applicable" to a hazardous substance, pollutant, contaminant, action being taken, location, or other circumstance, address problems or situations sufficiently similar to those encountered at the CERCLA site such that their use is well suited to the particular site. Once included in a Record of Decision, a requirement that is relevant and appropriate must be met as if it were applicable.
- TBC criteria are non-promulgated advisories or guidance issued by federal or state government that are not legally binding and do not have the status of potential ARARs. TBCs are evaluated along with ARARs and may be implemented by USEPA when ARARs are not fully protective of human health and the environment.

Onsite CERCLA response actions must meet substantive requirements but not administrative requirements. The NCP defines the term onsite as the areal extent of contamination and all suitable areas in close proximity to the contamination necessary for the implementation of the response action (40 *Code of Federal Regulations* [CFR] 300.5). Substantive requirements deal directly with actions or with conditions in the environment. Administrative requirements implement the substantive requirements by prescribing procedures, such as fees, permitting, and inspection, which make substantive requirements effective. This distinction applies to onsite actions only; offsite response actions are subject to all applicable standards and regulations, including administrative requirements such as permits.

Three classifications of requirements are defined by USEPA in the ARAR determination process: chemical-specific, location-specific, and action-specific, described as follows:

- Chemical-specific ARARs are health- or risk-management-based numbers or methodologies that result in the establishment of numerical values for a given medium, that would meet the NCP "threshold criterion" of overall protection of human health and the environment. These requirements generally set protective cleanup concentrations for the compound of concern in the designated media or set safe concentrations of discharge for a response activity.
- Action-specific ARARs are usually technology- or activity-based requirements or limitations on actions taken with respect to hazardous substances.
- Location-specific ARARs restrict response activities and media concentrations based on the characteristics of the surrounding environments. Location-specific ARARs may include restrictions on response actions near historic resources, within wetlands or floodplains, near locations of known endangered species, or on protected waterways. There are no known or suspected wetland areas or protected waterways within the site that would be disturbed during remedial action. Also, floodplains along the Lower Passaic River will remain undisturbed during the remedial alternatives identified in this FS. No endangered, threatened, or other species of special concern are identified within the site that would be disturbed during the remedial action (CH2M 2014a, Appendix I). No trees or structures that would be habitat of migratory birds will be disrupted. Therefore, threatened and endangered species, migratory bird, wetlands, and floodplain requirements are not ARARs for this FS. The only federal and New Jersey location-specific regulations that are ARARs for the proposed remedial actions are related to historic resources.

Section 121(d) of CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), requires attainment to the extent practicable of federal and state environmental or facility siting laws, when the state requirements are promulgated, more stringent than federal laws, identified by the state in a timely manner, and consistently applied. The Clean Water Act provisions to protect waters of the state are implemented by the NJDEP through state regulations; therefore, the state citations are provided as ARARs rather than the federal citations. The federal Clean Air Act provisions are similarly implemented by NJDEP. Regarding the RCRA, the state of New Jersey is authorized to implement RCRA. State requirements are considered to be "more stringent" if the state program has authorization and is at least as stringent as the federal program. This is the case in New Jersey; therefore, the state RCRA citations are provided as the ARARs.

4.2 Identification of Applicable or Relevant and Appropriate Requirements

Table 4-1 identifies the potential federal and state chemical-specific, action-specific, and location-specific ARARs for the site. The detailed evaluation of remedial action alternatives developed in this FS will include evaluation of whether the alternatives can achieve compliance with the federal and state ARARs presented in Table 4-1. NJDEP is the regulating entity for several of the identified ARARs. On CERCLA sites, only the substantive requirements of the ARARs need to be met. However, New Jersey follows a permit-equivalency process, and for some ARARs, input from the NJDEP is typically obtained. The following subsections describe some of the substantive requirements associated with key ARARs, the associated Division and Bureaus within NJDEP, and assumptions associated with development and evaluation of the alternatives.

4.2.1 Chemical-Specific

Cr(VI) contamination in groundwater is the main concern at the site, and therefore the National Primary Drinking Water Standards are considered to be an applicable ARAR. The NCP specifically states that maximum contaminant levels (MCLs) will be used as ARARs for useable aquifers rather than the more stringent maximum contaminant level goals. The aquifer beneath the site is considered to be a New Jersey Class IIA, and the New Jersey Class IIA GWQS for total Cr (70 µg/L) is more stringent than the federal drinking water standard (MCL of 100 µg/L). Therefore, the New Jersey GWQS represents the more protective ARAR for Cr in groundwater at the site.

There are no ARARs related to the RAO for basement surfaces contaminated by groundwater infiltration. Preliminary remediation goals (PRGs) were selected using a risk-based RAL that was developed specifically for the ECE property to prevent direct contact and ingestion of Cr(VI) concentrations from basement surfaces that exceed USEPA's acceptable risk range.

4.2.2 Action-Specific—New Jersey Pollutant Discharge Elimination System

For alternatives that include discharge of extracted groundwater, several discharge options are considered in this FS: discharge to surface water (DSW), discharge to publicly owned treatment works (POTW), and discharge/ reinjection back into the aquifer for the purpose of flushing/injecting reductants. The preferred choice of alternatives from an environmental and associated regulatory perspective is discharge to groundwater, followed by DSW, and the least preferred method is discharge to a POTW. The most appropriate option for the discharge of groundwater at the site will be identified during the design of the selected remedy.

4.2.2.1 Discharge to Groundwater through Underground Injection

Injection of waste and water into an aquifer is regulated through New Jersey's Pollutant Discharge Elimination System (New Jersey Administrative Code [NJAC] 7:14A), including Subchapter 7 Discharge to Groundwater and Subchapter 8 Underground Injection Control (UIC). Any flow rate of injection is regulated. Special-use wells handling nonhazardous injection fluids (such as the wells where reductants would be injected at the site) fall under a UIC Class V classification. Alternatives that include injection of groundwater and/or reductant would need to comply with the NJAC 7:14A Subchapters 7 and 8 requirements.

NJAC 7:14A Subchapter 7 imposes requirements for discharge to groundwater. Substantive aspects include no contravention of the GWQS at NJAC 7:9C or violation of the surface water quality standards at NJAC 7:9B, response to exceedances of such standards, soil and geologic evaluation, determination of depth to groundwater, and determination of background groundwater quality. Groundwater at the site contains Cr(VI) and other compounds at levels that exceed the New Jersey GWQS. Although the RAOs for the site are specific to Cr(VI), it is assumed that groundwater to be reinjected would need to meet New Jersey GWQS for all compounds.

NJAC 7:14A Subchapter 8 establishes controls to ensure that underground injection practices do not endanger underground sources of drinking water, and regulates the disposal of wastes by well injection. The rule is applicable to any well that is deeper than its largest surface dimension, where the principal function for the well is emplacement of fluids. Subchapter 8 prohibits the movement of injection fluids or contaminants into underground sources of drinking water; specifies construction, operating, maintenance, and plugging and abandonment requirements for wells; requires identification of all wells within a determined radius of the project site; determination of average and maximum daily rates and volume of injections and injection pressures; contingency plans; and assurance of mechanical integrity.

4.2.2.2 Discharge to Surface Water

The nearest surface water body is the Passaic River, which is classified as an FW2-NT/SE2 water, by the NJDEP. It is a non-trout, saline estuary water. For DSW, the effluent limitations would be those listed in Appendix B of the NJAC 7:14A-12 Effluent Standards Applicable to Direct Discharges to Surface Water and Indirect Discharges to Domestic Treatment Works (NJAC 7:14A-12 Effluent Standards). The NJAC 7:14A-12 Effluent Standards limits apply to any pollutant or pollutant parameter which either results from any remedial action or is present onsite at a concentration greater than the applicable surface water quality standards, unless approval is obtained from NJDEP. NJDEP may also impose limitations for additional pollutants based on specific rationale. NJAC 7:14A-12 Effluent Standards identify the effluent discharge level for Cr as 50 µg/L monthly average and 100 µg/L daily maximum.

Table 4-2 compares the average and maximum concentrations of Cr and other compounds found in groundwater at the site to their respective NJAC 7:14A-12 Effluent Standards. The average monthly limits are used where available. For compounds where a monthly average limit is not provided, the daily maximum limit was used. The comparison in Table 4-2 will serve as the basis for identifying the treatment processes that would be needed if extracted groundwater is discharged to surface water or a POTW.

4.2.2.3 Discharge to Publically Owned Treatment Works

The Passaic Valley Sewerage Commission (PVSC) manages the local POTW. Discharging extracted groundwater to PVSC's POTW would require PVSC approval to connect the discharge line to PVSC's sewer system, and to accept extracted groundwater for treatment. PVSC's regulations state that authorization to discharge groundwater, stormwater, and noncontact cooling water into their system, whether or not contaminated, will not be granted unless the person seeking such authorization demonstrates that there are no reasonable alternative means of disposing of the same, including, but not limited to, by directly discharging such wastes to surface waters.

If the groundwater is discharged to PVSC's POTW, PVSC's approval would specify the discharge limits and other requirements (for example, monitoring) for accepting the discharge. PVSC has established discharge limits for several metals (copper, lead, nickel, zinc, and mercury) and oil and grease. While Cr does not have an established limit, PVSC may establish a limit for Cr as well as for other contaminants in groundwater during the approval process. For metals with discharge limits, the average concentrations measured in groundwater at the site are less than PVSC's discharge limits. Therefore, for this FS, it is assumed that extracted groundwater to be discharged to the PVSC's POTW will not require any additional treatment beyond the ex situ system, prior to discharge.

This FS assumes that monthly monitoring of the discharged groundwater will be required for all discharge options.

4.2.2.4 Treatment Works Approval

The regulations in NJAC 7:14A Subchapters 22 and 23 describe requirements for facilities that are constructed and operated to collect, treat, or discharge domestic and industrial wastewaters, including extracted groundwater that is treated prior to discharge to surface water, a POTW, or returned to groundwater. The rules are applicable to building, installing, operating, or modifying treatment works; however, discharges authorized under NJAC 7:14-7.5 are exempt from these rules. At the site, substantive requirements of a treatment works approval would be met if not exempted. The technical requirements in Subchapter 23 are primarily geared toward domestic treatment operations rather than contaminated groundwater treatment. The rules acknowledge that is it the responsibility of the design engineer to design the treatment systems to meet all applicable rules, regulations, and local limits.

4.2.3 Action-Specific—Water Supply Management Act and Implementing Rules

NJDEP's Bureau of Water Allocation under the Division of Water Supply and Geosciences regulates extraction well(s), including those that exceed a combined pumping rate of 70 gpm (100,000 gallons per day). NJDEP uses a Bureau of Water Allocation CERCLA Application Permit Equivalency Form. Requirements include the following:

- Continuous recording of withdrawals.
- Within the zone of influence of the groundwater diversion, valid complaints by users of wells or surface water supplies are to be investigated to determine what impact the diversion has had on such wells or surface water supplies.

- The operation of the water withdrawal project cannot cause long-term progressive lowering of groundwater levels, permanent loss of storage capacity, or substantial impact on low flows of perennial streams or serve to spread the contamination.
- Whenever possible, the water is to be recharged after treatment, to the same aquifer from which it was withdrawn. Water should be reinjected on the same site from where it was withdrawn.

4.2.4 Location- Specific—Cultural Resources

The disturbance for most alternatives will be limited to the source area (where soils removal may occur) and existing roadways, rights-of-way, and paved areas (where wells, interconnecting piping, and the treatment system components would be installed). Additional evaluations would be needed to identify cultural resources. For this FS, it is anticipated that the groundwater treatment components can be situated in an area that will not disturb any critical environmental, historic sites, or natural heritage priority sites, if these are found to be present. Therefore, all alternatives are expected to be compliant with the National Historic Preservation Act and the New Jersey Register of Historic Places Act.

4.2.5 Location- Specific—Noise

Per the state noise control regulations (NJAC 7:29), the allowable levels at a residential property line from 7 AM to 10 PM are 65 A-weighted decibels (dBA) continuous and 80-dBA impulsive with octave levels as stated in the regulation. For residential areas from 10:00 PM to 7:00 AM, the allowable levels are 50-dBA continuous and 80-dBA impulsive with octave levels as stated in the regulation. The maximum allowable continuous and impulsive levels at the property line of industrial, commercial, community service, and public service properties, are the same as the daytime residential levels, with specific octave range levels as set in the regulation. While local requirements are not ARARs by definition, for the purpose of community relations, the City noise ordinance will also be complied with. The City of Garfield noise ordinances prohibits construction noise between 10:00 PM and 7:00 AM. It is expected that alternatives can be designed to meet these requirements.

4.3 Remedial Action Objectives

The NCP and USEPA's *Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites* (USEPA 1988b) define RAOs as medium- or site-specific goals for protecting human health and the environment that are established on the basis of the nature and extent of the contamination, the resources that are currently and potentially threatened, and the potential for human and environmental exposure.

Under CERCLA and the NCP (40 CFR 300), soil and groundwater remedial actions must (1) be protective of human health and the environment and (2) meet ARARs (or satisfy criteria for an ARAR to be waived). RAOs are general descriptions of what the remedial action is expected to accomplish. They are defined as specifically as possible to address the following concerns:

- Media of interest (for example, soil and groundwater)
- Types of contaminants
- Potential receptors (human and ecological)
- Exposure pathways (direct contact, ingestion, or inhalation)
- Contaminant concentrations that may remain in the environmental media once the remedial action is complete

The RAOs for contaminated groundwater at the site were developed in collaboration with USEPA and USACE based on the understanding of the CSM at the time of preparation of this report. RAOs and PRGs will be finalized in the Record of Decision for the site.

The following are the RAOs:

- **RAO 1.** Restore groundwater to beneficial use where Cr concentrations exceed the New Jersey GWQS.
- **RAO 2.** Prevent ingestion of groundwater with Cr concentrations above the New Jersey GWQS.
- **RAO 3.** Minimize the potential for infiltration of Cr(VI)-contaminated groundwater into basements and transfer of Cr(VI) onto basement surfaces.
- **RAO 4.** For basement surfaces contaminated by groundwater infiltration, prevent direct contact and ingestion of Cr(VI) concentrations on basement surfaces that exceed USEPA's acceptable risk range.

For RAO 1, beneficial use is defined as New Jersey Class II A groundwater, which is the classification for groundwater suitable for drinking water purposes. The alternatives that more effectively achieve RAO 1 (restore groundwater to beneficial use) will also achieve RAOs 2, 3, and 4.

4.4 Preliminary Remediation Goals

PRGs are site-specific, quantitative goals that define the extent of cleanup required to achieve the established RAOs. In general, PRGs are conservative, media-specific concentrations of COCs that are protective of human health and the environment.

The groundwater Cr(VI) PRGs selected to address RAOs 1 and 2 is 70 µg/L, based on the New Jersey GWQS for total Cr. Additionally, the Cr(VI) PRG for vadose zone soils within the ECE property is 20 mg/kg, based on the RAL (NJDEP 2007b), which was selected for source zone soils within the ECE property. No PRGs were developed for saturated zone soils.

Multiple Cr(VI) PRGs have been developed to address RAOs 3 and 4 based on the presence of multiple forms on impacted media, including standing water, solid residual in basements with high use, and solid residual in basement with low use, described as follows:

- Standing water in basement: 70 µg/L
- Soils within the ECE property (vadose zone): 20 mg/kg
- Basement—High Use: 110 $\mu g/m^3$ or 1.1 µg per wipe
- Exposure time: 8 hours for soft surface (6 hours for ages 7 to 18); 4 hours for hard surface (2 hours for ages 7 to 18)
- Exposure duration: 350 days per year for 30 years
- Basement—Low Use: 870 $\mu g/m^3$ or 8.7 µg/wipe
- Exposure time: 150 minutes/day (60 minutes/day ages 0 to 10)
- Exposure duration: 5 days/week (2 days/week ages 6 to 18)

4.5 Remediation Target Areas

Remediation target areas (RTAs) are the areas where contaminant concentrations in target media exceed their established PRGs.

The source zone RTA is defined as the boundaries of the ECE property, which encompass Cr(VI)-impacted soil, overburden groundwater, and bedrock groundwater beneath the ECE property. The limits of the RTA of affected groundwater exceeding the PRG of 70 µg/L are shown in Figures 2-4 and 2-5 for the overburden aquifer and bedrock aquifer, respectively. The overburden area is also considered the RTA for basement groundwater intrusion exceeding PRGs.

SECTION 5

Identification and Screening of Remedial Technologies

5.1 General Response Actions

General response actions (GRAs) consistent with the RAOs and PRGs presented in Section 4 are identified in this section. GRAs are basic actions that might be undertaken to remediate a site and are assembled based on the nature and extent of contamination. For the site, GRAs and associated technologies were evaluated for the source area, overburden groundwater plume, and bedrock groundwater plume. The source area includes the overburden and bedrock plumes within the footprint of the former ECE property.

For each GRA, several possible remedial technologies may be available, which can be further broken down into a number of process options. The GRAs identified to address the Cr(VI) contamination in groundwater at the site, consistent with the established RAOs and PRGs, are as follows:

- No action
- Institutional controls (ICs)
- Monitoring
- Groundwater extraction, treatment, and discharge
- In Situ treatment
- Containment
- Removal
- Technologies to minimize infiltration into basements

5.1.1 No Action

The no action response entails no further action to remove, remediate, monitor, or restrict access to the groundwater other than what has already been implemented. The no action response is required by the NCP as a baseline against which all other alternatives are compared.

5.1.2 Institutional Controls

ICs are non-engineered, administrative, and/or legal controls that help to minimize the potential for human exposure to contamination and/or protect the integrity of a remedy. ICs work by limiting land or resource use and/or by providing information that helps modify or guide human behavior at the site. For groundwater, ICs may include restrictions on groundwater use, which include installing and using potable wells or productions wells until the PRGs are achieved. ICs are not currently in place at the site.

5.1.3 Monitoring

Groundwater monitoring is conducted to provide a better understanding of the presence, concentration trends over time, and persistence of contaminants in groundwater. Groundwater monitoring is used to confirm that plumes are not expanding or migrating into areas where exposure might occur above risk-based levels. Monitoring is also performed in conjunction with other remedial actions to track remedial progress.

Monitored natural attenuation (MNA) is a monitoring program that is designed to evaluate the natural attenuation processes that are occurring in the aquifer. It can be considered a remedial technology and component of a remedial alternative if the natural attenuation processes are adequate to achieve the RAOs and PRGs. MNA is distinguished from no action in that natural attenuation assumes contaminant concentrations are being reduced and/or attenuated by various naturally occurring physical, chemical, and biological processes. The primary natural attenuation processes are dilution, dispersion, biological and chemical reduction, volatilization, and adsorption. Under this general response action, unaugmented, natural, intrinsic processes reduce contamination concentrations, and a monitoring program would be implemented to track remedial progress.

As presented in *Use of Monitored Natural Attenuation at Superfund, Resource Conservation and Recovery Act Corrective Action, and Underground Storage Tank Sites* (USEPA 1999), MNA is an appropriate remedial response only where its use will be protective of human health and the environment, and when it will be capable of achieving site-specific RAOs within a timeframe that is reasonable compared with other alternatives. The NCP preamble suggests that a “reasonable” timeframe for a remedy relying on natural attenuation is generally a “timeframe comparable with that which could be achieved through active restoration” (USEPA 1990). MNA is frequently paired with active remedies that address the source of contamination. Largely because of the uncertainty associated with the potential effectiveness of MNA to meet remediation objectives that are protective of human health and the environment, USEPA expects that source control and long-term performance monitoring will be fundamental components of any MNA remedy.

The primary natural attenuation processes for Cr(VI) are dilution, dispersion, biological and abiotic reduction, and adsorption. *Monitored Natural Attenuation of Inorganic Contaminants in Ground Water Volume 2: Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium* (USEPA 2007), presents a tiered approach to evaluating the applicability of MNA for Cr(VI) sites. Tier 1 involves demonstrating that the plume is static or shrinking, has not reached compliance boundaries, and does not impact existing water supplies. Cr sequestration in aquifer solids is justification for proceeding to Tier II characterization efforts. *Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites* (USEPA 2015) also presents a phased analysis approach to MNA, with Phase 1 requiring demonstration that the groundwater plume is not expanding.

The following summarizes the evaluation of the overburden Cr(VI) plume against the Tier 1/ Phase 1 criteria for MNA viability:

- The extent of the plume defined by groundwater data from 2011 through 2014. Long-term Cr(VI) concentration trends are not available to evaluate if the plume is static or shrinking. The Phase 2 groundwater model shows that the plume will eventually contract, especially if source treatment is implemented.
- The geochemistry in the overburden aquifer indicates that groundwater is moderately oxidizing on average, which likely limits abiotic and microbial reduction of Cr(VI).

Based on the Tier 1/Phase 1 criteria, MNA was not retained for further consideration as part of the potential remedies for the overburden aquifer. Future monitoring and modeling of the overburden plume may demonstrate that natural attenuation processes are occurring and the MNA evaluation would be reviewed.

5.1.4 Groundwater Extraction, Treatment, and Discharge

In this response action (also known as pump-and-treat), groundwater would be extracted from the aquifer using vertical or horizontal pumping wells. The groundwater would then be pumped to an ex situ treatment, where contaminants would be removed from the influent water stream. The following subsections detail the remedial technologies and applicable process options.

5.1.4.1 Extraction

This remedial technology involves collecting contaminated groundwater through a network of extraction wells (vertical or horizontal) or trenches. For the site, the selected process option would involve installing new extraction wells to capture contaminated groundwater.

5.1.4.2 Ex Situ Treatment

Following extraction of groundwater, groundwater is treated with ex situ methods to reduce contaminant mass and/or toxicity and remove it from the water stream. The following ex situ treatment process options were identified:

- Ion exchange
- Chemical reduction and precipitation
- Electrocoagulation
- Wetlands
- Subgrade bioreactors (SGBRs)
- Bioreactors
- Phytoremediation
- Membrane separation (reverse osmosis)

Ion Exchange. Ion exchange is a non-destructive technology, meaning that removal of contaminants is achieved through mass transfer as extracted contaminated groundwater is typically pumped through columns containing an anion exchange resin that removes Cr(VI). Ion exchange resins can be made of synthetic or inorganic natural polymeric materials. Once the resin capacity has been exhausted, resins can be regenerated for reuse or, in the case of high-capacity, single-use resins, be disposed as appropriate.

Chemical Reduction and Precipitation. Ex situ chemical precipitation involves introducing chemicals to transform dissolved contaminants into insoluble solids, which are removed by sedimentation and filtration. Chemicals used to remove Cr(VI) can include ferrous chloride, ferrous sulfide, zero-valent iron (ZVI), sulfur dioxide, and various sulfites. Ferrous iron is commonly used for industrial wastewaters, such as wastes generated by metal plating processes. Solids removal processes typically include flocculation and/or coagulation, settling, and filtration. Sludge handling, dewatering, and disposal are also required. The volume and/or mass of the sludge generated can be extremely large and would require final disposal at a disposal facility. Site-specific testing would be required to obtain design and operational parameters.

Electrocoagulation. Electrocoagulation is a specific form of chemical reduction and precipitation. It is used to remove a variety of suspended solids and dissolved pollutants from aqueous solutions, including Cr(VI). An electric field is applied to metal plates, which release ions into the water. To remove oxidized species such as Cr(VI), iron plates typically are used. The iron ions produced reduce Cr(VI) to Cr(III), in an iron-chromium hydroxide form, which subsequently is removed from the water via the solids removal discussed above.

Wetlands. Constructed wetlands act as biofilters for removing contaminants. Constructed surface flow treatment wetlands are typically shallow, custom-made impoundments planted with emergent, rooted vegetation. Water flows over land through the wetland and primarily above the sediment surface. A constructed wetland typically would require a much larger area and a much longer hydraulic retention time compared to a bioreactor (described below), but it typically would not require added nutrients and would require less operational oversight. Wetlands are used to treat groundwater, industrial wastewater, and municipal wastewater. Cr(VI) can be removed in wetlands primarily by microbiological and chemical reduction. Some Cr(VI) uptake by wetland plants may also occur.

SGBRs. Biological treatment using SGBR is a potential treatment technology for Cr(VI) in groundwater. If implemented on a full scale, a SGBR may consist of a lined excavation backfilled with a mixture of sand/gravel, a biodegradable substrate such as wood mulch, and possibly ZVI. The contaminated groundwater would pass through the basin in which the Cr(VI) is chemically and/or biologically reduced to Cr(III). A second stage aeration/filtration basin could be provided to remove residual organic carbon that may be present and remove dissolved byproducts of biodegradation (ferrous iron, arsenic, and manganese), as well as suspended solids, before discharging the treated groundwater back to the aquifer or a surface water body.

Bioreactors. Ex situ bioreactors can be used to biologically reduce and precipitate Cr(VI). Groundwater is amended with an electron donor (carbon source) and passed through a matrix with microbial films where contaminants are biologically reduced. The types of matrices available include fixed beds, fluidized beds, and membranes. Similar to SGBRs, a second-stage aerobic reactor would be required.

Phytoremediation. Phytoremediation is using plants and microorganisms associated with plant roots to extract, evapotranspire, immobilize, contain, or degrade contaminants. In the case of Cr(VI), degradation would not be among the phytoremediation mechanisms, although it is conceivable that microorganisms could reduce reducible metals to some unknown extent. Phytoremediation is typically used as a polishing step and not for high concentrations of contaminants. For groundwater, phytoremediation is limited to the depth to which the plants can extract water. For plumes at great depths, groundwater could first be extracted (by pumping) and then phytoremediated (that is, the plants would be irrigated with the contaminated groundwater). Phytoremediation systems (including by irrigation) are only operational when the soil is warm and plants are active, so treatment effectiveness would be reduced in the winter. The land requirements for phytoremediation are also relatively large.

Membrane Separation (Reverse Osmosis). Reverse osmosis is a pressure-driven process that uses semipermeable membranes to purify water. Contaminated water is passed through the membrane while the contaminants are contained within the membrane. The water that is allowed to pass through the membrane is called the permeate and typically contains only a small fraction (less than 5 percent) of the ions in the feed solution. The water that does not pass through the membrane (containing the ions that do not pass through the membrane) is called the retentate or brine, concentrate, or reject. It has a high TDS concentration and would contain most of the contaminants of potential concern being treated. With appropriately sized membranes and multiple stages of membranes, very low concentrations of ions can be achieved.

5.1.4.3 Discharge

Once contaminated groundwater is extracted and treated through ex situ treatment, it would be discharged. The following discharge process options were identified:

- Groundwater injection wells
- Surface infiltration
- Beneficial reuse of treated water
- Discharge to a local publicly owned treatment works
- Surface water discharge (through a New Jersey Pollutant Discharge Elimination System [NJPDES])

Discharge options would require compliance with ARARs (discharge limits), which would not be limited to Cr(VI) but would include all contaminants present in the discharge as well as the physical characteristics of the discharge (such as temperature and pH). These treatment options will be defined for the selected discharge options. Using targeted reinjection or infiltration can have secondary benefits in that they can be focused to enhance the flushing of the Cr(VI) mass from the subsurface. They can also be used to create mounding of groundwater levels, which may modify the flow path of the contaminated groundwater.

5.1.5 In Situ Treatment

In Situ treatment entails treating the groundwater while it remains in the aquifer. Treatment for Cr(VI) generally includes applying methods to immobilize this contaminant by physical or chemical methods (USEPA 2000a).

The following in situ process options were identified:

- In Situ chemical reduction

- In Situ biological treatment (anaerobic)
- Flushing
- Soil mixing

In Situ Chemical Reduction. Chemical reducing agents such as calcium polysulfide (CaSx) or sodium dithionite are injected or mixed into the contaminated groundwater plume to transform Cr(VI) to less-mobile and less-toxic Cr(III), thereby facilitating lower concentrations of Cr in groundwater. Once Cr(III) is formed, it precipitates as a stable low-solubility hydroxide phase (for example, Cr(III) hydroxide; Eary and Rai 1987). Alternative chemical-reducing agents include ferrous sulfide, ferrous sulfate, and ZVI.

In Situ Biological Treatment (Anaerobic). Enhanced in situ bioremediation for Cr(VI) in oxygenated groundwater typically employs the injection or infiltration of organic carbon compounds (substrates such as EVO, lactate, ethanol, cheese whey, sugar syrups, and proprietary mixes) to stimulate microbial activity and lower the redox state within the subsurface.

In Situ bioremediation is an effective method for imposing reducing conditions on a targeted zone of an oxidizing aquifer to reduce soluble and mobile Cr(VI) to Cr(III). As with chemical reduction, once Cr(III) is formed, it precipitates as a stable, low-solubility hydroxide phase [Cr(III) hydroxide].

Flushing. Flushing involves injecting clean or treated water into a zone of contaminated groundwater to expedite remediation of the plume. A groundwater collection or extraction system must be designed to ensure complete hydraulic control and contaminant recovery. Flushing can be combined with ex situ pump-and-treat remedies to help increase the effects of the flushing and to maintain hydraulic control of flushing fluids in order to minimize downgradient impacts to the aquifer.

Soil Mixing. Soil mixing involves the subsurface mixing of unsaturated or saturated soils with an amendment, such as bentonite grout or chemical reducing agent, to modify the physical or chemical characteristics of the soil without the need for excavation of the contaminated material. Soil mixing can be carried out either through direct application and mixing using an excavator, or through drilled columns, in which amendments are injected into the subsurface and mixed using large augers. Soil mixing could be used to reduce migration of contamination from the source area to the downgradient groundwater plume by treating the source area saturated soils and shallow bedrock.

5.1.6 Containment

Containment refers to minimizing the spread of groundwater contaminants by using the following methods:

- Active hydraulic gradient control (for example, pumping/extraction wells)
- Passive hydraulic gradient control (for example, vertical subsurface barriers)
- Permeable reactive barriers (PRBs) or reactive zones (which can be chemical or biological)

Active and passive hydraulic control provides containment through physical means. PRBs are porous walls or zones in the subsurface installed across and through the groundwater contamination plume and contain reactive material that degrades or adsorbs contaminants as groundwater flows through the wall. Reactive material can be chemical or biological in nature. Common reactive media used in PRBs are ZVI and bioremediation amendments such as EVO. PRBs can be used in conjunction with a passive gradient control to form a funnel and gate system.

According to USEPA (1988b), conditions that favor the use of stand-alone containment remedies include the following:

- Low-mobility contaminants
- Low aquifer transmissivity
- Low contaminant concentrations
- Low potential for exposure

- Low projected demand for future use of the groundwater

Containment techniques are also typically used in conjunction with other source and plume remediation techniques near a source area or to prevent exposure of the contaminants to receptors downgradient of the plume.

For management of contaminated groundwater at the site, the following containment process options were identified:

- Containment wall (slurry wall or sheet pile wall)
- Biological PRB
- Chemical PRB (using soluble chemicals or ZVI)
- Hydraulic containment via extraction

No containment technologies were retained for the site, based on the mobility and concentrations of Cr and the potential exposure in basements.

5.1.7 Removal

This action involves removing contaminated material through excavation, disposal, and backfill. Excavated soil would be segregated to decide on appropriate disposal or treatment requirements, and all material above the applicable standards would be removed. Treatment of contaminated material may be needed before disposal at an appropriate facility. Technologies to implement excavation vary based on depth and complexity. Deeper excavation would require more-complex methodologies, for example using soldier piles and dewatering.

USEPA has already carried out removal of unsaturated fill and overburden soils at the ECE property.

5.1.8 Technologies to Minimize Infiltration into Basements

The following technologies were considered to minimize the potential for infiltration of Cr(VI)-contaminated groundwater into basements, transfer of Cr(VI) onto basement surfaces, and exposure to Cr(VI):

- Dewatering of basements where dewatering is needed to prevent infiltration
- Basement cleaning and waterproofing

5.1.8.1 Basement Dewatering

Dewatering involves preventing the infiltration of Cr(VI)-contaminated groundwater into basements. Dewatering can be completed by installing French drains where this is needed. French drains are trenches covered with gravel or rock or containing a perforated pipe to redirect groundwater away from the basement.

5.1.8.2 Basement Cleaning and Waterproofing

This involves cleaning affected basements and applying a sealant to basement floors and walls to prevent future infiltration of Cr(VI) contaminated groundwater. USEPA is implementing this approach at the site where needed.

5.2 Technology Screening Process and Evaluation Criteria

Technology screening was conducted following the technology screening guidance described in the USEPA *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA 1988a). Potential remedial technologies and process options were screened according to the following three established criteria:

- Technical effectiveness

- Implementability
- Cost

5.2.1 Technical Effectiveness

The technical effectiveness of a technology/process option was evaluated based on its ability to meet the RAOs under the conditions and limitations present at the site. The technical effectiveness criterion was used to determine which remedial technologies would be effective based on the nature and extent of contamination, site characteristics, and other engineering considerations. The NCP defines effectiveness as the "degree to which an alternative reduces toxicity, mobility, or volume through treatment, minimizes residual risk, affords long-term protection, complies with ARARs, minimizes short-term impacts, and how quickly it achieves protection." Remedial technologies that are not likely to be effective for addressing groundwater contamination at the site are screened out and not retained for further evaluation.

5.2.2 Implementability

Implementability refers to the relative degree of difficulty anticipated in implementing a particular technology/process option under the regulatory and technical constraints posed at the site. Implementability is evaluated in terms of the technical and administrative feasibility of constructing, operating, and maintaining the technology/process option, as well as the availability of services and materials. Technical feasibility refers to the ability to construct, reliably operate, and comply with regulatory requirements during implementation of the technology/process option. Technical feasibility also refers to the future operation, maintenance, and monitoring after the technology/process option has been completed. Administrative feasibility refers to the ability to coordinate with and obtain approvals and permits from regulatory agencies. Availability of services and materials may include the availability and capacity of treatment, storage, and disposal services; the availability of bulk materials; and the requirements for and availability of specialized equipment and technicians. Remedial technologies that cannot be implemented at the site are screened out and not retained for further evaluation.

5.2.3 Cost

The primary purpose of the cost-screening criterion is to allow for a comparison of rough costs associated with the technologies/process options. The cost criterion addresses costs to implement the technology/process option and long-term costs to operate and maintain the remedy. At this stage of the process, the cost criterion is qualitative and used for rough comparative purposes only.

5.3 Screening of Remedial Technologies and Process Options

The GRAs identified in the preceding section were broken down further into potential remedial technologies and process options, as summarized in Table 5-1. These potential remedial technologies and process options were then evaluated or screened based on their implementability; effectiveness in eliminating, reducing, or controlling risks to human health and the environment; and relative cost.

Table 5-1 presents the identified technologies and process options and the results of the screening. The various technologies screened include demonstrated and proven processes, innovative technologies, and potential processes that have undergone laboratory trials or bench-scale testing. Factors considered in the evaluation included the state of the technology's development, site conditions, nature and extent of contamination, and presence of constituents that could limit the effectiveness of each technology. Ratings of low, moderate, and high were assigned for each technology and are relative to the other technologies evaluated considering the factors mentioned above.

Technical implementability is the first screening criteria evaluated as part of this process, in accordance with USEPA guidance. However, for technologies with significant technical implementability challenges, effectiveness and cost were still evaluated to allow for a more complete evaluation. Technologies that were considered technically impracticable based on challenges associated with existing site conditions (lithology, depth), a potential increased risk to worker safety, or of increased complexity compared to other technologies of comparable effectiveness were screened out. Technologies were also removed from further consideration if they were considered to have limited treatment effectiveness for the specified contaminant of potential concern or performance uncertainties.

5.4 Results of Technology Screening Using Established Criteria

As presented in Table 5-1, the following are the general response actions and the remedial technologies/process options retained following screening to address Cr(VI) contamination in groundwater at the site:

- No action
- ICs
- Monitoring
- Groundwater extraction, treatment, and discharge (pump and treat)
  - Groundwater extraction
  - Ex situ ion exchange
  - Ex situ chemical reduction and precipitation
  - Ex situ bioreactors
  - Discharge via groundwater injection wells, POTW, and surface water (NPDES)
- In Situ treatment
  - In Situ chemical reduction
  - In Situ biological treatment (anaerobic)
  - Flushing
  - Soil mixing
- Removal
  - Excavation (source area only)
- Minimize infiltration into basements
  - Dewatering
  - Basement cleaning and waterproofing

Technologies that were considered not technically implementable or feasible based on implementability, effectiveness, and cost were screened out. The list of retained options is considered dynamic, flexible, and subject to revision as progress is made throughout the FS process and additional information becomes available. An evaluation of the state and potential full-scale application of innovative technologies that were not retained may also be considered during the 5-year review process once additional information on these technologies becomes available. The technologies selected based on this screening were combined into a range of remedial alternatives, as reported in Section 7.

SECTION 6

Technical Impracticability Determination

Section 6 presents an evaluation of and justification for a TI waiver of specific ARARs for the bedrock groundwater Cr(VI) plume at the site. The bedrock groundwater plume is being considered for a TI waiver for the reasons discussed in the following subsections. The overburden plume is not being considered for a TI waiver because Cr(VI) in overburden groundwater poses a human health risk. This evaluation has been prepared in accordance with the USEPA Office of Solid Waste and Emergency Response (OSWER) Directive 9234.2-25, *Guidance for Evaluating the Technical Impracticability of Groundwater Restoration* (TI Guidance) (USEPA 1993).

Remedial Investigation data, along with information on the site setting, have identified critical limitations to bedrock groundwater restoration. This TI evaluation demonstrates the impact of these critical limitations on the restoration potential with currently available remedial technologies. This evaluation is presented in the following sections:

1. **ARARs:** Summarizes site-specific ARARs for the bedrock groundwater plume.
2. **Site Conditions:** Summarizes the CSM for the bedrock groundwater plume and fate and transport characteristics of Cr(VI) in bedrock.
3. **Evaluation of Potentially Applicable Technologies:** Presents limitations of currently available remedial technologies, and presents the results of fate and transport modeling performed for the site, which provides an assessment of bedrock remedial cleanup timeframes.
4. **Stability of Groundwater Plume**: Describes the predicted bedrock plume behavior under current conditions.
5. **TI Zone:** Describes the area over which the TI waiver decision would apply.
6. **Source Remediation:** Describes historic and potential future Cr(VI) source remediation activities.
7. **Alternate Remedial Strategy:** Proposes the alternate plume management strategy that would be implemented if a TI waiver is granted to protect human health and the environment.

6.1 Applicable or Relevant and Appropriate Requirement

The site-specific, chemical-specific ARARs under consideration under this TI evaluation are the chemical-specific cleanup levels for groundwater that would meet the NCP threshold criterion of overall protection of human health and the environment. For the bedrock groundwater Cr(VI) plume, the chemical specific ARARs include the following:

- National Primary Drinking Water Standards MCL for total Cr of 100 µg/L
- New Jersey GWQS Class IIA for total Cr of 70 µg/L

For the TI evaluation, the more conservative New Jersey GWQS standard will be used as the groundwater cleanup standard.

6.2 Site Conceptual Model

6.2.1 Site Location and Description

The site is located primarily in the southwestern portion of the city of Garfield in Bergen County, New Jersey. The city of Garfield is highly urbanized and is composed of residential neighborhoods, local government buildings, and commercial properties. According to the 2010 U.S. Census, the city of Garfield is home to approximately 30,500 residents with a population density of roughly 14,525 people per square mile. Based on a review of current aerial maps, the majority of the properties within the plume boundary are developed, with little to no public green space or parks. The presence of the bedrock plume beneath the highly urbanized and densely populated city areas and the abundance of utilities in the streets pose severe constraints on performing groundwater remediation in the bedrock aquifer.

The current boundaries of the bedrock groundwater plume extend west from the former ECE facility past the Passaic River to the city of Passaic, north to Van Winkle Avenue, and south just past Hudson Street (Figure 2-5).

6.2.2 Historical Potential Sources of Contamination

There are two documented spills at the site. In December 1983, the flange at the bottom of the 7,900-gallon vertical storage tank failed, releasing an estimated 3,640 gallons of chromic acid directly into the shallow aquifer. Following the spill, a groundwater recovery well was installed and operated for 4 months. Based on diminishing recovery of Cr mass and suspected contaminant migration into bedrock, the system was shut down. In May 1996, an additional spill was reported at the ECE facility in which approximately 250 gallons of process wastewater flowed from the building onto Sherman Place. The Bergen County HazMat team responded and mitigated the spill using absorbent pads.

In 2013, MVS software was used to prepare a 3D model of the Cr(VI) plume and provide an order-of-magnitude approximation of the mass in the plume resulting from the releases at the ECE property. The MVS model results suggest that the current mass of Cr(VI) in the groundwater plume may be up to four times the amount reportedly released during the 1983 and 1996 spills, indicating that unreported spills or leaks may have occurred historically at the former ECE facility (CH2M 2014a).

One additional historical potential source of contamination is the T.A. Farrell Electroplating Facility, a separate former electroplating facility located approximately 1,600 feet to the southwest, down/cross-gradient of the ECE property (Figure 1-2). Historically, no releases of Cr were reported at the T.A. Farrell Electroplating Facility. However, in 2007, an RI report for the T.A. Farrell Electroplating Facility indicated that total Cr exceeded criteria in 3 of 17 groundwater samples. A select number of onsite T.A. Farrell wells are part of the overall monitoring well network associated with the site.

6.2.3 Bedrock Geology

The Passaic Formation (Brunswick aquifer) beneath the site consists of thinly interbedded micaceous siltstones, mudstones, and fine- to medium-grained sandstones with minor occurrences of rounded, fine- to coarse-grained sandstones. In addition to abundant mechanical breaking that predominantly occurred along bedding partings, frequent fractures were observed in rock cores from the site. The natural fractures are generally highly weathered with staining from mineral oxidation along the margins of the fracture, suggesting that water migrates through the fractures. Many fractures are partially to completely infilled with white mineralization, possibly calcite, although the mineralogy was not field-verified. Fracture inclination ranged from near-horizontal (0°) to subvertical (70°).

Natural gamma ray responses from downhole geophysical logs indicate the presences of three discrete sandstone units (upper, middle, and lower sandstones) across the site. The upper sandstone averaged 9 feet in thickness, the middle unit averaged 6 feet in thickness, and the bottom unit had an average thickness of 15 feet. Each layer appears to dip at an angle consistent with regional bedding, with dip consistently increasing to the west. An analysis of the geophysical log from well EPA-18-BR, located near the center of the site, shows an average bedding strike of 145° southeast, dipping at 14°southwest.

6.2.4 Bedrock Hydrogeology and Hydrogeologic Investigations

The most recent potentiometric surface map generated during December 2014 (Figure 1-10) shows that groundwater flow in bedrock is consistent with regional groundwater trends flowing from the east toward west within the main study area in Garfield. Groundwater flow in the Brunswick aquifer is oriented toward the west with preferential flow through a discontinuous network of fractures and bedding parting. The potentiometric surface elevation observed across the site varies from approximately 5 to 45 feet amsl in bedrock. The similarity in water level elevations suggests that the Brunswick aquifer present in bedrock may be unconfined or semiconfined and hydraulically connected to the overburden aquifer. Hydraulic gradients in the bedrock ranged from 0.0054 to 0.25 ft/ft, with an average gradient of 0.014 ft/ft across the site from east to west. Within bedrock, the distribution of vertical heads suggests mixed downward and upward flow regimes until closer to the Passaic River, where potentiometric heads progressively increased with depth, suggesting more consistent upwards flow.

Flownet modeling analysis was performed as part of the RI (CH2M 2014a) to evaluate the relationship between groundwater and the Passaic River. Based on the analysis, flow through the overburden into the Passaic River comprises around 65,500 gallons per day of the total groundwater flow out the western boundary of the site. Vertical flow from the bedrock aquifer up into the overburden contributes around 9,400 gallons per day of the flow that discharges into the Passaic River. Approximately 56,000 gallons per day flows out the western boundary of the site (beneath the Passaic River) through discrete bedrock aquifer units and relatively impermeable rock units separating these aquifer units.

Hydrogeologic investigations show that the hydraulic conductivity within the bedrock can vary over several orders of magnitude, indicating a complex fractured rock system with areas of limited transmissivity, as follows:

- In 2007, a hydrogeology study focused on bedrock was performed at the former Kamala Chemical property. Results of the study indicated a hydraulic conductivity ranging from 0.005 to 2.5 ft/d, with an average value of 0.56 ft/d in the bedrock (Sovereign Consulting Inc. 2008).
- During the RI, hydraulic packer testing and FHCP was conducted at various depth intervals throughout the bedrock. FHCP returned transmissivity values ranging from 0.23 to 50.3 ft^2/d (CH2M 2014a). Packer testing showed transmissivity values in bedrock ranging from 0.11 to 1,045 ft^2/d, resulting in hydraulic conductivity values ranging from 0 for 52.27 ft/d. Unlike the geophysical logging results from the RI that offered correlative features (sandstone beds, fracture zones, fracture orientation, etc.) between adjacent boreholes, packer testing and FLUTe results showed greater variability. A borehole displaying several zones of elevated hydraulic conductivity values was often located adjacent to a borehole(s) exhibiting very low values.
- Results of 2013 aquifer testing conducted at EPA-21-BR (see Appendix A) showed that well yield in the bedrock aquifer can be highly variable, and that at some locations the expected design pumping rates for a pump-and-treat system (assumed to be 10 gpm per well on average taking into consideration the variability) would not be sustainable without excessive drawdown.

6.2.5 Bedrock Contaminant Distribution, Fate, and Transport

Cr(VI)-impacted groundwater migrates through the bedrock aquifer mainly through secondary (fracture) porosity. The bedrock aquifer is conceptualized as a system of stacked, leaky-confined aquifer systems connected by through-going vertical fractures. The bedrock is composed of sandstones, siltstones, and shale and exhibits little primary (matrix) porosity. In addition to the individual fractured zones, three sandstone beds influence the location of the fracture networks at depths between 80 and greater than 200 feet bgs. These sandstone beds exhibited greater average hydraulic conductivities than other zones in finer-grained rocks. However, hydrogeologic investigations showed that there is no discernible correlation between the distribution and/or magnitude of hydraulic conductivity values in similar lithologic (sandstone beds) and fracture attributes. This heterogeneity ultimately influence groundwater flow, solute transport, and preferential pathways across the site. As a consequence, it can be concluded that no dominant groundwater flow paths exist in the bedrock aquifer, and flow downgradient of the ECE property is likely to be heterogeneous and tortuous.

Cr(VI) concentrations decrease along the central axis of the bedrock plume, with maximum concentrations detected in the source area, and lower concentrations detected near the Passaic River. Cr(VI) has migrated to depths exceeding 300 feet bgs; however, the highest concentrations were found at depths ranging from 60 to 130 feet bgs. The bedrock plume currently covers approximately 160 acres.

The general chemistry of the bedrock aquifer is oxidizing. The pH of the bedrock groundwater is neutral to alkaline, ranging between 7 and 10 in shallow to intermediate depths, and 9 to 13 at depths greater than 200 feet. These measurements are on the groundwater that flows through the fractured network and may not represent the porewater in the rock matrix. The oxidizing nature and relatively high pH of the groundwater limits abiotic reduction, microbial reduction, and sorption of the Cr(VI).

The University of Guelph performed a matrix diffusion study in 2012 (University of Guelph 2013) to evaluate the distribution of Cr(VI) in the rock matrix versus fractures to assess whether matrix diffusion is an important process affecting Cr(VI) fate and transport. A total of 100 rock core samples from EPA-21-BR over a depth interval of 69 to 355.5 feet bgs and were analyzed for Cr(VI) concentrations in the rock matrix. The resulting porewater concentrations were compared to groundwater concentrations from sampling of FLUTe ports at EPA-21-BR. Overall results of the study suggest that significant matrix diffusion has occurred in the shallower intervals (down to 117 feet bgs) given that the porewater concentrations were as high or higher than the groundwater concentrations measured in FLUTe ports. These are also the depths with the highest groundwater concentrations. Deeper depths had less Cr(VI) in the rock matrix porewater, but also less in the groundwater. Due to the inherent concentration variability expected in fractured sedimentary rock, more sample analyses would be required to adequately define the Cr(VI) concentration and mass distribution within other regions of the bedrock aquifer.

6.2.6 Groundwater Flow and Chromium Transport Modeling

A numerical model of the site was built using the groundwater flow and solute transport modeling software MODFLOW-SURFACT (HydroGeoLogic 1996). The numerical model was carried out in two phases, building and calibrating the groundwater flow model (Phase I) and building a contaminant transport model that used flow data from the Phase I model (Phase II).

The Phase I model was set up as five separate stratigraphic layers over an area of 3.3 square miles, with 50-foot grid spacing. General head boundary conditions were setup on the east and west boundaries of plume, with the Passaic River as the boundary condition in the overburden layer. The Phase II model used the flow model framework to conduct dual-domain transport simulations, with a mobile domain modeled by well-connected fractures or pore spaces and contaminant transport dominated by advection, and an immobile domain modeled by poorly connected pores (such as rock matrix) and contaminant transport dominated by diffusion. Contaminant exchange between the two domains takes place solely via diffusion.

The numerical model was used to help evaluate the practicability of meeting ARARs in bedrock groundwater with a combined site remedy that also includes source and overburden plume treatment, as described in Section 6.3.2. Details of the numerical model can be found in the *Garfield Groundwater Contamination Superfund Site Phase 1 Groundwater Flow Modeling Technical Memorandum* (CH2M 2014c) and the *Garfield Groundwater Contamination Superfund Site Phase 2 Solute Transport Modeling Technical Memorandum* (CH2M 2015b) included in Appendix C.

6.2.7 Water Supply Wells

A city production wellfield consisting of three wells is located approximately 0.8 mile north-northeast from the ECE property in Columbus Park. Although these wells have been inactive for several years, there may be a potential for these wells to return to service in the near future. The combined total pumping capacity from these wells is approximately 600 gpm, which may be sufficient to draw Cr(VI) from the site toward the production wells, or affect the design and operation of a remediation system.

In 2006, a 72-hour aquifer test was conducted at one of the three production wells, GAR-1A. The well was pumped at its forecasted future production rate of 290 gpm. The resultant zone of influence (where drawdown was detected during pumping) extended to within approximately 2,000 feet of the ECE facility. Full 600-gpm pumping from the entire production well field likely would cause this zone to extend considerably further.

6.2.8 Potential Ecological and Human Receptors

The site is located in an urbanized area consisting of residential neighborhoods, local and federal government buildings, and commercial properties. Groundwater in the vicinity of the site is currently not used as a potable or municipal source of water, and as such there are no current human receptors using the groundwater. However, as discussed in Section 6.2.7, if one or more of the three production wells located approximately 0.8 mile north-northeast from the ECE property are put back into service, there is a potential that Cr(VI) from the bedrock plume will be drawn toward the production wells.

Based on the results of the SLERA and BERA, potential complete exposure pathways for ecological receptors exist where groundwater discharges to the Passaic River. However, results of the risk assessments indicate that Cr concentrations in surface water do not represent a potential risk to aquatic life, there is negligible potential for Cr in sediment and surface water to represent a risk to mammalian and avian wildlife, and Cr from groundwater discharging to the Passaic River poses no threat to the benthic community.

6.3 Evaluation of Potentially Applicable Technologies

Select remedial technologies retained in Section 5 are further evaluated in this section for their practicability and potential effectiveness in treating the bedrock aquifer. Although it was not retained in Section 5, MNA is further evaluated for the bedrock aquifer to support the TI evaluation. Table 6-1 presents those technologies and process options and the results of the additional screening specific to site conditions in the bedrock aquifer.

The bedrock remedial technologies retained for further evaluation include the following:

- MNA
- In Situ treatment (biological)
- Groundwater extraction, treatment, and discharge (pump and treat)

ICs and groundwater monitoring would be implemented in conjunction with either technology as part of the bedrock remedy.

6.3.1 Technology Limitations

To be successful, a remedial technology would have to be capable of treating Cr(VI) in both the rock matrix and the bedrock fractures. To do this, the technology must be capable of maintaining that contact over a long enough period to successfully treat contamination. None of the potential technologies are capable of achieving these goals, described as follows:

MNA: The primary natural attenuation processes for Cr(VI) are dilution, dispersion, biological and abiotic reduction, and adsorption. *Monitored Natural Attenuation of Inorganic Contaminants in Ground Water Volume 2: Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium* (USEPA 2007), presents a tiered approach to evaluating the applicability of MNA for Cr(VI) sites. Tier 1 involves demonstrating that the plume is static or shrinking, has not reached compliance boundaries, and does not impact existing water supplies. Cr sequestration in aquifer solids is justification for proceeding to Tier II characterization efforts.

The following summarizes the evaluation of the bedrock Cr(VI) plume against the Tier 1 criteria for MNA viability:

- The extent of the plume is defined by groundwater data from 2011 through 2014. Long-term Cr(VI) concentration trends are not available to evaluate if the plume is static or shrinking. The Phase 2 groundwater model (see Section 6.3.2) shows that the plume will eventually contract over hundreds of years.

- Results of x-ray diffraction and total organic carbon analysis in bedrock samples did not indicate the presence of significant quantities of minerals or organic carbon that could react with Cr(VI).
- The geochemistry in the bedrock aquifer indicates that groundwater is moderately oxidizing on average, which likely limits abiotic and microbial reduction of Cr(VI).

Based on the Tier 1 criteria, MNA should not be retained for further consideration as part of the potential remedies for the bedrock aquifer. However, future monitoring and modeling at the site may demonstrate that natural attenuation processes are occurring.

Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites (USEPA 2015) also presents a phased analysis approach to MNA, with Phase 1 requiring demonstration that the groundwater plume is not expanding. Future monitoring and modeling of the bedrock plume may demonstrate that natural attenuation processes are occurring and the MNA evaluation would be reviewed.

In Situ treatment (Biological): Given the large size of the bedrock plume, access limitations in the neighborhoods, and the need for long-term treatment of Cr(VI) that would slowly diffuse out of the hydraulically disconnected portions of the aquifer and bedrock matrix, the most likely form of in situ treatment would be creating in situ reduction barriers using a slow-release substrate such as EVO. The barriers would comprise hundreds of injection wells installed along neighborhood streets, and would require reinjection every 3 to 5 years. Although mobile groundwater flowing through the barriers would be treated, a majority of the Cr(VI) mass residing in disconnected fracture networks and the rock matrix would not be treated. Furthermore, the ability to more aggressively treat areas of immobile groundwater via direct contact with injected substrates would be severely limited by the access constraints in the highly urbanized and densely populated neighborhoods. Because of these technical and logistical constraints, in situ treatment would have limited effectiveness in remediating the bedrock plume in a timely manner.

Pump and Treat: Pump and treat would involve extracting groundwater from the bedrock aquifer using vertical or horizontal pumping wells, followed by ex situ treatment and discharge. For a vertical well network, 10 to 15 extraction wells and associated conveyance piping would be installed along neighborhood streets. Although groundwater in mobile fractures of the bedrock aquifer would be extracted, the majority of the Cr(VI) mass residing in disconnected fracture networks and the rock matrix would not be treated. As discussed in Section 6.2.4, the hydraulic conductivity within the bedrock can vary over several orders of magnitude, indicating a complex fractured rock system with areas of limited transmissivity. Results of 2013 aquifer testing conducted at EPA -21-BR (see Appendix A) also showed that at some locations in the bedrock, the expected design pumping rates for a pump-and-treat system (approximately 10 gpm per well on average) could not be sustained without excessive drawdown. Therefore, the efficiency of an extraction well network would in reality be much less than expected due to certain wells producing little water or having poor connection with fracture zones. The access constraints in the highly urbanized and densely populated neighborhoods would limit where additional wells and piping could be installed to make up for these inefficiencies. Because of these technical and logistical constraints, pump and treat would have limited effectiveness in remediating the bedrock plume in a timely manner.

6.3.2 Bedrock Groundwater Plume Modeling

To further assess the likely performance of bedrock plume remediation, contaminant fate and transport modeling was performed using MODFLOW/SURFACT to evaluate the practicability of meeting ARARs in bedrock groundwater with a combined site remedy that also includes source and overburden plume treatment. The model was carried out in two phases, as detailed in the *Garfield Groundwater Contamination Superfund Site Phase 1 Groundwater Flow Modeling Technical Memorandum* (CH2M 2014c) and the *Garfield Groundwater Contamination Superfund Site Phase 2 Solute Transport Modeling*

Technical Memorandum (CH2M 2015b) included in Appendix C. A discussion of the models setup and results are summarized in the following subsections.

6.3.2.1 Phase 1

Phase 1 consisted of building and calibrating a groundwater flow model, representing five separate stratigraphic layers (overburden, weathered bedrock, and three layers of bedrock) over an area of 3.3 square miles, with 50-foot grid spacing (CH2M 2014c). General head boundary conditions were setup on the eastern and western boundaries of the plume, no flow boundaries were set up on the northern and southern boundaries of the plume, and the Passaic River was implemented as a boundary condition in the overburden layer. Natural groundwater flow in the model is toward the Passaic River, which is considered the lowest point of hydraulic head. A recharge rate of 8 inches per year, based on regional rainfall data, was incorporated at the upgradient boundary.

The groundwater flow model (GFM) provided the basis for the contaminant transport model (CTM) built during Phase 2. The CTM used the same model grid layout, boundary conditions, and hydraulic properties as the GFM. To provide more vertical resolution for defining the Cr plume, the upper bedrock layer (Model Layer 3 from the GFM) was divided into two layers in the CTM. The average layer thicknesses in the CTM were as follows:

- Overburden—49 feet
- Weathered Bedrock—19 feet
- Upper Bedrock—50 feet
- Upper Middle Bedrock—50 feet
- Middle Bedrock—100 feet
- Lower Bedrock—277 feet

6.3.2.2 Phase 2

Phase 2 consisted of building a CTM for Cr(VI), but incorporating the flow model from Phase 1 to determine groundwater flow velocities and calculate contaminant migration through the flow field. The Phase 2 model used a dual-domain transport simulation, with a mobile domain modeled by well-connected fractures and contaminant transport dominated by advection, an immobile domain used to model the rock matrix, and contaminant transport dominated by diffusion. Contaminant exchange between the two domains takes place solely via diffusion. The dual domain allowed for the accurate modeling of immobile Cr(VI) contained within the rock matrix, and the influence that rebound from this immobile mass had during implementation of potential remedial actions. In model simulations, the rate of this diffusive mass transfer is governed by a mass transfer coefficient. The mass transfer coefficient is not easily measured in the field, and varies according to the age of the plume. The mass transfer coefficient is also affected by the degree of proximity or "average distance" between the mobile and immobile domains. The bedrock mass transfer coefficient was set to 8.8e-6 days^{-1}, one-fifth of the overburden value of 4.4e-5 day^{-1}, to reflect the increased length scale between the relatively sparse fractures and the center of the unfractured blocks in the bedrock matrix.

Cr(VI) concentrations from samples collected during the RI (CH2M 2014a) and December 2014 (Figure 2-5) were used to develop the Phase 2 model. The groundwater concentrations were incorporated in the mobile domain and were used to develop the immobile domain concentrations, based on an assumed established equilibrium within the plume over time.

The sorption of anionic Cr(VI) was considered likely to be minor, so a low sorption coefficient value of 0.05 liter per kilogram (L/kg) was assigned. This equates to a retardation coefficient of 2.1 in the fractured bedrock. The bedrock immobile porosity of 10 percent was obtained from the University of Guelph Matrix Diffusion Study (2013). The bedrock fracture porosity was derived from a tracer test in the Passaic Formation described by Payne et al. (2008) from which the mobile porosity of the formation was estimated to be between 0.1 and 0.7 percent. From this range, a bedrock mobile porosity of 0.5

percent was selected for the present modeling effort. The longitudinal dispersivity of Cr(VI) at the site was estimated to be 39.2 feet, with transverse and vertical dispersivity being 10 percent of that value (3.92 feet). A diffusion coefficient of 0.0013 square feet per day was assumed. It was assumed that there was no natural degradation of Cr(VI) in the aquifer.

6.3.2.3 Bedrock Modeling and Remedial Timeframe Estimates

Three remediation scenarios were modeled to estimate the likely cleanup timeframe for the bedrock plume. Two of the scenarios include treatment elements for the source and/or overburden plume, which represents the most likely scenario if bedrock remediation were implemented. The remediation scenarios included the following:

- **Bedrock Remediation Scenario 1: No Further Action.** This simulation does not incorporate any treatment in the source zone, overburden, or bedrock.

  Figures C-19 and C-20 in Appendix C show the model forecasted concentrations in Model Layers 3 (upper bedrock) and 5 (middle bedrock) for the no action scenario. As expected, the plume shows some diminishment of concentrations and plume area over time, but the change is slow. The model does suggest some increase in plume concentrations in the middle bedrock between 0 and 15 years. The estimated timeframe for 90 percent reduction in the aerial footprint of the bedrock plume exceeding the NJDEP GWQS for Cr is 400 years. The estimated timeframe to achieve the GWQS across the entire plume is greater than 500 years, the maximum time period of the model simulations.

- **Bedrock Remediation Scenario 2: Source Treatment.** This simulation assumes soil mixing with an in situ reductant will be performed to remediate the saturated overburden and weathered bedrock inside the ECE property boundary. Pump and treat and in situ reduction to remediate the shallow bedrock below the ECE property is also assumed. This simulation does not incorporate any treatment in the overburden or bedrock plumes.

  Figures C-21 and C-22 in Appendix C show the results for the source treatment only scenario for the same model layers. The source area remediation is estimated to reduce plume concentrations but appears to do little to reduce the footprint of the plume until later times. The estimated timeframe for 90 percent reduction in the aerial footprint of the bedrock plume exceeding the NJDEP GWQS for Cr is 370 years. The estimated timeframe to achieve the GWQS across the entire plume is 460 years.

- **Bedrock Remediation Scenario 3: Source Treatment with Pump and Treat in the Bedrock and Overburden Plumes.** This simulation includes the same source treatment as Scenario 2, with the addition of pump and treat within the overburden and bedrock groundwater plumes using 15 extraction wells in each aquifer installed to 350 and 50 feet bgs, respectively. Groundwater is assumed to be extracted at a rate of approximately 8 gpm per well, treated ex situ, and discharged to the Passaic River. In the model, pump and treat for the overburden and bedrock plume is assumed over in situ treatment because it expected to be more cost-effective (see Table 6-1).

  Figures C-23 and C-24 in Appendix C show the results for the source and plume treatment scenario. The plume remediation appears to have an effect on the bedrock plume area over time; however, large areas of the plume persist at concentrations well above 70 µg/Leven after a century of continuous pumping. The estimated timeframe for 90 percent reduction in the aerial footprint of the bedrock plume exceeding the NJDEP GWQS for Cr is 192 years. The estimated timeframe to achieve the GWQS across the entire plume is 250 years.

Actual bedrock cleanup timeframes may be much longer than what is estimated by the MODFLOW/SURFACT model. Groundwater models do not have the capability to simulate discrete fractures or to adequately incorporate the small-scale variability in fracture connectivity that is inherent in fractured rock aquifers. Therefore, the efficiency of groundwater extraction and Cr(VI) mass removal may be much less than modeled. Furthermore, additional extraction wells would be needed to account for wells that produce little water, redundant wells extracting form the same fracture network, poor connection between wells and fracture zones, and to avoid excessive drawdown that could potentially dewater the fracture network or pull contaminants down from the overburden.

6.3.3 Bedrock Remediation Case Study: Naval Air Warfare Center, West Trenton

Case studies were reviewed to further evaluate the potential performance of remedial technologies in bedrock in New Jersey. An example case study is Naval Air Warfare Center (NAWC), which has been the subject of an active remediation program since 1993. Although chlorinated solvents are the primary COCs at the NAWC facility, the limitations of long-term pump and treat and in situ remediation in the Brunswick aquifer due to a complex fractured bedrock system with dead-end fractures that have been observed at NAWC, are applicable to the TI evaluation for the site.

The sedimentary fractured bedrock at the NAWC facility is similar to the bedrock at the site and has been extensively characterized using similar methods (rock matrix COC characterization, borehole geophysical testing, and multilevel groundwater monitoring well installation). The current remedial system is based on pumping and treatment of impacted groundwater and has been operating since 1997. The concentrations of COCs in groundwater have generally decreased since 1997 (approximately 100,000 to 10,000 µg/L), but have remained greater than GWQS.

An in situ remediation pilot study was also conducted to evaluate whether source treatment could potentially accelerate the shut-down of the groundwater extraction system. The study included injecting EVO into two well pairs. The total size of the treatment area was approximately 9,000 square feet and extended 120 feet bgs. Extracted water from one well was dosed with the injection materials and injected into its paired well within the test plot area. The results of the pilot showed that COC concentrations in the test area were reduced. However, rebound from the low permeability and hydraulically disconnected portions of the rock matrix resulted in contaminant rebound, which necessitated additional donor injections.

These data indicate that pump and treat and in situ treatment are not effective in addressing the COC mass residing in the primary immobile porosity and in low hydraulically conductive fractures in the bedrock matrix, and that rebound of COCs to groundwater will necessitate the long-term operation of the facility groundwater extraction remedy.

6.4 Stability of Groundwater Plume

As discussed in Section 6.3.2, modeling shows that the bedrock groundwater plume footprint would generally be stable over the next 10 to 15 years, with some increase in plume concentrations in the middle bedrock, and some higher concentrations evolving at the source area in the upper bedrock. The plume begins to slowly shrink thereafter over hundreds of years.

These model results are consistent with the current CSM of the bedrock plume, which has Cr(VI) migrating to deeper depths, but decreasing in concentration to below detection limits as the plume flows towards and beneath the Passaic River. This plume edge attenuation coincides with dilution and dispersion, and also to a small extent upward flow into the overburden aquifer, which subsequently discharges to the regional discharge zone represented by the Passaic River.

As discussed in Section 6.2.4, a small percentage of the bedrock aquifer flows up into the overburden at the western end of the site, which eventually discharges to the Passaic River. Any minor contribution from the bedrock aquifer to the total discharge of groundwater to the Passaic River (estimated to be approximately 14 percent of the total discharge) is not expected to have a significant impact on ecological receptors at the river. Based on the results of ecological risk assessments performed for the site (Section 2.2.3), there is little to no potential adverse effects to benthic organisms, nor to aquatic, mammalian, or avian wildlife, due to the discharge of Cr(VI) to the river sediments and surface water.

Overall, modeling results and the current understanding of the bedrock plume CSM show that minimal growth of the Cr(VI) plume footprint or migration downgradient is anticipated to occur. Accordingly, a defined TI zone for the bedrock groundwater plume can be established and maintained.

6.5 Technical Impracticability Zone

The USEPA TI Guidance states that at sites where restoration of groundwater to its most beneficial use is technically impracticable, the area over which the decision applies (referred to as the TI zone) generally will include all portions of the contaminated groundwater that do not meet ARARs. ARARs are waived inside the TI zone and other measures, such as pathway elimination and/or administrative controls, are used to prevent exposure to human health and the environment. Outside of the TI zone, ARARs will still apply.

In accordance with the TI Guidance, a TI zone has been developed for the bedrock groundwater Cr(VI) plume that meets these criteria. The parameters for the TI zone are presented in the following subsections.

6.5.1 Horizontal Extent

The horizontal extent of the TI zone is defined by the current boundaries of the bedrock groundwater Cr(VI) contamination plume exceeding the New Jersey GWQS for Cr of 70 µg/L. The plume boundary extends from the former ECE property on the east, west past the Passaic River into to the city of Passaic, north to Van Winkle Avenue, and south just past Hudson Street (Figure 2-5). The horizontal extent of this area is based on data from 2014, and may need to be expanded or reduced based on future data collected.

6.5.2 Vertical Extent

Cr(VI) concentrations exceeding the New Jersey GWQS of 70 µg/L have been detected at depths exceeding 300 feet bgs within the bedrock aquifer, as shown in Figures 1-6, 1-7, and 1-8. The depth of the bedrock groundwater Cr(VI) plume at the ECE facility is at an elevation of approximately 0 feet North American Vertical Datum of 1988 (NAVD88), and increases moving west to a maximum depth at Midland Avenue at an elevation of -300 feet NAVD88, and then decreases moving further west beyond the Passaic River into the city of Passaic to a depth at -125 feet NAVD88.

The vertical extent of the TI zone is assumed to extend from the bedrock contact with the overburden (ranging from +35 feet NAVD88 at the ECE facility to -45 feet NAVD88 west of the Passaic River) down to the bottom of the 70 µg/L bedrock plume (ranging from 0 feet NAVD88 at the ECE facility to -300 feet NAVD88 at Midland Avenue). The vertical extent of the TI zone is shown in Figure 6-1.

6.6 Source Remediation

When restoration of groundwater to beneficial uses is not practicable, potential sources of contamination must still be addressed. The following source area removal actions and pilot tests have been completed to date, as described in Sections 2 and 3:

- Following the 1983 spill of 3,640 gallons of chromic acid, a groundwater recovery well was installed and operated for 4 months.
- In 2011, hazardous materials at the ECE property were inventoried, categorized, and stabilized. These materials were removed from the site and disposed of offsite in January 2012.
- In July 2012, building materials within the ECE facility were found to contain elevated levels of Cr(VI) and total Cr. In October 2012, the facility was demolished, leaving behind two basements and concrete slab footprint where the building previously stood.
- Between October 2013 and May 2014, Cr(VI)-impacted soils, concrete basements and slab, onsite vats/tanks, and other debris were excavated and removed from the ECE property. The vertical

extent of the excavation was limited to the unsaturated overburden above the water table. A total of 5,687 tons of soil exceeding RAL of 20 mg/kg and 1,180 tons of contaminated concrete were removed.

- An in situ reduction pilot study was carried out at the ECE property in 2014 to investigate the practicability of injecting reagents into the overburden with direct push technology, achievable reduction of Cr(VI) mass in the overburden groundwater, and the practicability of creating reducing zone barriers as part of a full-scale remedy. Results of the performance monitoring indicated in situ reduction has the potential to be successfully implemented to remediate Cr(VI) directly outside the overburden source area, due in part to the low pH of the source area.

As part of this FS, additional source remedial alternatives for the saturated overburden and weathered bedrock underlying the source area at the ECE property were also evaluated. Although the proposed TI zone includes the entire bedrock aquifer, treatment of the shallow bedrock below the ECE property will also be evaluated to treat Cr(VI) concentrations in bedrock, which have been detected at a maximum concentration of 86,500 µg/L, at ECE-10-BR in 2012. The immediate goal of this shallow bedrock treatment will not be to achieve ARARs in bedrock below the source area, but to remediate source mass to the extent practicable to minimize Cr(VI) mass flux to the downgradient bedrock plume.

6.7 Alternative Remedial Strategy

With the granting of a TI waiver, an alternative remediation strategy must be developed. With a TI waiver for this site, USEPA proposes to implement ICs and monitoring as the Alternative Remedial Strategy (ARS). The proposed ARS would protect human health and the environment through the implementation of land use controls and groundwater use limitations until contaminant concentrations meet the New Jersey GWQS of 70 µg/L.

The ARS monitoring program will be designed to measure Cr concentrations, geochemical parameters (e.g., pH, DO, ORP, anions), and hydrogeologic parameters (e.g., hydraulic gradients and flow direction). The data will be used to evaluate the behavior of the bedrock aquifer Cr(VI) plume over time, including the following:

- Changes in three-dimensional plume boundaries of the Cr(VI) plume
- Changes in the geochemistry and redox state that may indicate changes in the rate and extent of potential Cr(VI) attenuation, or the stability of reduced Cr(III) in the aquifer
- Mobile contaminant mass and concentration reductions indicative of progress toward RAOs

Monitoring to detect plume expansion and potential impacts to receptors will be met through monitoring wells sidegradient and downgradient of the plume boundaries, beneath the plume, and near any other compliance boundaries specified in remedy decision documents in conjunction with monitoring of possible receptor locations. Monitoring locations between the plume and compliance boundaries or possible receptors should be close enough to the plume that a contingency plan can be implemented before the contaminant can move past the point of compliance or impact receptors.

Quarterly monitoring would be conducted for several years to establish baseline conditions over a period of time sufficient to observe seasonal trends, determine trends at new monitoring points, plume responses to recharge, and to confirm key hypotheses of the conceptual site model. The monitoring plan will specify an approach and technical criteria that could be used to increase or reduce the monitoring frequency as conditions change. Such criteria would scale monitoring frequency to match the level of understanding and confidence in the conditions that control attenuation at the site. The ARS monitoring plan will be a dynamic document that can be modified as conditions change or the conceptual site model is revised to reflect new information. Criteria for modifying the monitoring program, including the type and amount of data needed to support the evaluation, will be defined in the monitoring plan.

Following implementation of the ARS and based on the results of groundwater monitoring in the bedrock groundwater plume, reduction or expansion of the TI zone may be considered. The protectiveness of the ARS will be ensured through the groundwater monitoring program. Additional response actions may be taken to ensure protectiveness, based upon whether the ARS is achieving the required performance standards.

6.8 Summary of the Restoration Potential

Based on this TI evaluation, and following USEPA guidance (USEPA 1993), the following is a summary of the potential for restoration of the bedrock groundwater plume to the ARARs:

- The sources of contamination have been identified on the ECE property. Removal of much of the source has been performed through the previous removal action conducted by the USEPA. As discussed in the following sections of this FS, additional source zone remedial actions are being considered.
- Pilot tests of in situ reduction have also been implemented in the overburden on the ECE property. These tests and the source removal do not, in the short term, impact the bedrock groundwater plume, so no data are available on their impacts to the bedrock aquifer.
- An assessment of other bedrock remedial technologies was performed. No technology was deemed able to reliably, logically, or feasibly attain the cleanup levels within a reasonable timeframe for the following reasons:
  - MNA was judged not to be a viable technology at this time based on the general oxidizing geochemistry of the groundwater and the lack of other data to support a Tier 1 MNA evaluation.
  - The bedrock plume exists beneath highly urbanized and densely populated city areas and the abundance of utilities in the streets pose severe constraints on performing groundwater remediation. For example, the hundreds of wells that would be required for in situ treatment was deemed to be impracticable.
  - The bedrock groundwater flow system is very complex and composed of a discontinuous network of fractures and bedding parting. Further, it can be concluded that no dominant groundwater flow paths exist in the bedrock aquifer, and flow downgradient of the ECE property is likely to be heterogeneous and tortuous. As a consequence, capturing the plume with a pump-and-treatment system would be very difficult, and require a large number of deep extraction wells. Complete capture and removal of the plume is judged to be impracticable.
  - There are likely numerous poorly connected fractures that may act as reservoirs for Cr(VI) impacted groundwater, as well as Cr(VI) in the rock matrix. These may both result in slow diffusion out into the mobile fracture network which carries the bulk of the flowing groundwater. As a result, remediation of the bedrock plume using either pump and treat or in situ treatment would be difficult because disconnected fracture networks and the rock matrix would not be remediated, likely resulting in contaminant rebound once active remediation ceases.
- Predictive analysis of timeframes to attain required cleanup levels was performed using groundwater plume modeling. With additional source zone treatment and combined overburden and bedrock pump-and-treatment systems, the modeling predicts a timeframe of 250 years to achieve the cleanup levels across the entire bedrock plume. This timeframe is deemed to be not reasonable.

Restoration of the bedrock plume is deemed to be impracticable. Given this, USEPA is proposing that a front-end TI waiver be granted for the bedrock groundwater Cr(VI) plume at the site. The TI waiver would apply to the TI Zone discussed in the previous subsections, and the alternative remedial strategy discussed in Section 6.7 would be implemented.

SECTION 7

Development, Screening, and Analysis of Remedial Alternatives

Section 7 presents development, screening, and evaluation of remedial alternatives that will address the RAOs for the site. The remedial alternatives were developed by assembling the remedial technologies and process options retained in Section 5. Section 7 also defines the criteria to be used in screening and evaluating alternatives, describes the alternatives, and analyzes them individually and comparatively using the established evaluation criteria.

7.1 Summary of Alternatives

7.1.1 Rational for Assembly of Alternatives

Development of remedial alternatives must conform to the requirements identified in CERCLA, as amended, and to the extent possible, the NCP. CERCLA Section 121(d) requires that Superfund remedial actions attain ARARs to the extent possible, unless specific waivers are granted, and the remedial actions must also be protective of human health and the environment. CERCLA Section 121(b) and the NCP identify the following statutory preferences when developing and evaluating remedial alternatives:

- **Use treatment to address principal threats wherever practicable**. In Situ and ex situ treatment options were incorporated into the alternatives for the site.
- **Use a combination of methods, as appropriate, to achieve protection of human health and the environment**. The remedial alternatives for the site are various combinations of ICs, in situ treatment, groundwater extraction and treatment, and monitoring.
- **Use institutional controls as needed to supplement engineering controls to prevent or limit exposure**. ICs will be incorporated into the remedy for the site as needed to assist in maintaining long–term groundwater use control and aquifer pumping to control exposure to impacted groundwater.
- **Consider using innovative technologies when they offer the potential for comparable or superior treatment performance or implementability**. Innovative in situ and ex situ treatment technologies have been incorporated into the alternatives; in particular, in situ reduction and soil mixing at the ECE property have been evaluated as a potential measure for reducing the Cr(VI) concentrations.
- **Prevent further migration of groundwater plumes and exposure to contaminants in groundwater**. The alternatives include a source treatment component that will address ongoing migration of Cr(VI) in groundwater.

The assumptions and other factors summarized in the following paragraphs were used as a basis to guide development of the remedial alternative for the source area and overburden aquifer. These assumptions are supported by the nature of the site setting and by the available site characterization data. Potential areas of uncertainty to be considered in the selection of the preferred remedial alternative are also identified.

It is assumed that a TI waiver will be granted within the bedrock plume TI zone discussed in Section 6.

It is assumed that there is currently a continued source of contamination on the ECE property, associated with impacted soil below the water table in the overburden and in the shallow bedrock.

The high density of buildings, roadways, and other infrastructure systems at the site will make implementation of any active remediation of the downgradient overburden plume challenging. Those alternatives that require more disruption of the infrastructure (for example, more wells) will be more challenging and thus will rank lower in terms of implementability. The conceptual designs developed for the alternatives discussed below were based on being reasonably implementable. More aggressive alternatives (for example, alternatives that might have additional wells dispersed throughout the neighborhoods) were not included since there were deemed to be not implementable.

ICs will be implemented as a component of the alternatives, with the exception of no further action, to help prevent exposure to contaminated groundwater. These ICs may include a Classification Exception Area and a Well Restriction Area.

For cost estimates only, it is assumed that all the remedial alternatives have a timeframe of 30 years, in accordance with CERCLA guidance for monitoring results. The 30-year technical analysis and costs evaluations are presented in the FS for consistency between alternatives.

It is assumed that future development of the site will be coordinated with, and will not impede the implementation of, the remedial alternatives.

7.1.2 Development of Alternatives

Based on the rationale presented in the previous paragraphs, and the technology and process options that have been retained after screening, the following alternatives are proposed for the site:

- Alternative 1: No Action
- Alternative 2: Source Treatment
  - 2A: Source treatment using soil mixing in the overburden and pump and treat for the shallow bedrock
  - 2B: Source treatment using in situ injections in the overburden and pump and treat for the shallow bedrock
  - Ongoing basement investigation and remedial actions including dewatering and cleaning/ waterproofing, as needed
- Alternative 3: Source Treatment and In Situ Reduction Barriers for Overburden
  - Source zone treatment selected from Alternative 2
  - Creation of in situ reduction barriers in the downgradient overburden plume
- Alternative 4: Source Treatment and Pump and Treat for Overburden
  - Source zone treatment selected from Alternative 2
  - Extraction and ex situ treatment of groundwater with opportunity for reinjection or discharge to POTW or surface water
- Alternative 5: Source Treatment, and combined Pump and Treat and In Situ Reduction Barriers for Overburden
  - Source zone treatment selected from Alternative 2
  - Extraction and ex situ treatment of groundwater with opportunity for reinjection or discharge to POTW or surface water
  - Creation of in situ reduction barriers in the downgradient overburden plume

7.2 Detailed Descriptions of Alternatives

7.2.1 Alternative 1: No Action

Per the NCP requirement, the no action alternative is carried through the entire FS process as the baseline condition against which the performance of the remaining alternatives is evaluated.

Under the no action alternative, no remedial actions would be taken to reduce the levels of contamination in the source area or downgradient plume. Additionally, this option does not include the continuation of any existing institutional controls, nor the implementation of any new institutional controls. Any improvement of groundwater quality would be through natural attenuation, including biological and abiotic reduction, adsorption or diffusion into the rock matrix, dispersion, and dilution.

7.2.2 Alternative 2: Source Treatment

Under Alternative 2, the focus of the remedial action would be confined to the saturated soils, weathered bedrock material, overburden aquifer, and shallow bedrock aquifer within the confines of the ECE property. Several remedial technologies, either by themselves or in combination, could be used to address impacts in the source area, including pump and treat, in situ reduction, soil mixing, and/or excavation. Excavation, although considered a feasible technology that has already been conducted extensively at the ECE property, will not be considered under this FS as a primary treatment technology. Excavation however could be used as a supplemental process to support other technologies for contaminated media not amenable to pump and treat, in situ reduction, or soil mixing (e.g., large pieces of contaminated concrete).

For alternative development in this FS, two combinations of technologies were assumed for the Alternative 2 source treatment. Alternative 2A is a combination of the following:

- Soil mixing of the overburden and weathered bedrock, including the addition of a reducing agent and possibly a low-permeability additive (i.e., bentonite, cement, etc.)
- Pump and treat and in situ reduction in the shallow bedrock

Alternative 2B is a combination of the following:

- In Situ injections of a reducing agent in the overburden and weathered bedrock through permanent injection points
- Pump and treat and in situ reduction in the shallow bedrock

The optimal remedial design, including well field design, treatment and disposal process options, and reagent selection, will be developed during the remedial design phase through laboratory test, field test, and detailed design optimization. For the alternative evaluation in this FS, the design parameters included in Table 7-1 and further discussed in the following subsections will be assumed.

7.2.2.1 Alternative 2A—Soil Mixing Component

Soil mixing would be carried out within the overburden and weathered bedrock by thoroughly mixing that material with a reducing agent, such as CaSx, ZVI, or sodium dithionite. The reducing agent would chemically convert Cr(VI) to Cr(III). An agent to reduce the hydraulic conductivity after the mixing could also be added. Bentonite clay or a pozzolontic agent such as cement could be added. Reducing the hydraulic conductivity in the source zone reduces the Cr(VI) flux out of the zone even further by preventing groundwater from flowing through the zone.

The target treatment zone for the soil mixing is shown in plan view in Figure 7-1, and in the cross-section in Figure 7-2. The target treatment zone covers the depth of the high water table to the top of the competent bedrock (a depth ranging from 7 to 10 feet in thickness). As a result of the 2014 USEPA soil removal activities, in which vadose zone materials with elevated Cr(VI) concentrations were removed, it is assumed that Cr(VI) in the soil above the high water table is below concentrations that could potentially leach significant Cr(VI) mass.

Soil mixing would be performed by dividing the site into sections, approximately 150 feet x 150 feet, in order to facilitate the logistics involved with the process. The following steps would be implemented one section at a time for soil mixing:

- Clean vadose zone soil would be removed and stockpiled on site from the section being treated. Approximately 3 feet of soil above the water table would be left in place to provide a stable working platform for the mixing equipment.
- A slurry containing the reducing agent and bentonite (or equivalent) would be added to the mixing area and a backhoe would be first using to thoroughly mix the overburden soil.
- A specially designed mixing head would then be used to complete the mixing process in order to break apart any residual clumps of soil that were not broken up by the backhoe.
- A backhoe with ripper teeth would then be used to loosen and mix the weathered bedrock to the extent possible. The loosed rock material would then be mixed with the soil above it.
- Samples would be collected and tested in the field to confirm even distribution of the reducing agent throughout the section
- A pozzolanic agent could then be mixed with the material, as needed, to facilitate the operation by creating a hard surface for later working on the material.

The specific details of the operation and sequencing will be developed in the design process and will be specific to the contractor selected for the work. The assumed volume of soil to be treated via soil mixing is approximately 4,667 cubic yards within the saturated overburden and weathered bedrock.
An estimated 1,525,615 pounds of CaSx (30 percent by weight solution) would be added during soil mixing. A portion of the remaining 8,000 cubic yards of unsaturated soil above the water table will be excavated and/or managed to provide equipment access the saturated overburden and weathered bedrock for mixing. It is anticipated that the soil mixing would take approximately 4 months to implement.

7.2.2.2 Alternative 2B—In Situ Injections in Overburden and Weathered Bedrock

In Alternative 2B, in situ injections would be carried out within the overburden and weathered bedrock within the source area. The injections would be conducted through permanent injection wells. Approximately 45 injection wells would be installed, as show in plan view in Figure 7-3. The wells would be screened across the saturated overburden and the weathered bedrock as shown in the cross-section in Figure 7-4. A reducing agent, such as CaSx or sodium dithionite, would be injected into the saturated subsurface to chemically convert Cr(VI) to Cr(III). An estimated 508,538 pounds of CaSx (30 percent by weight solution) would be injected during the initial event. Each injection event will take approximately 6 days to complete. For this evaluation, it is assumed that subsequent reinjections would be carried out annually for 6 years. Four additional monitoring wells would be installed throughout the source zone, and monitored to determine when follow up injections are required.

7.2.2.3 Source Zone Bedrock Aquifer Treatment

In addition to one of the two treatment technologies for overburden and weathered bedrock, the following components common to both sub-alternatives would be implemented.

Pump and treat would be carried out within the shallow bedrock aquifer within the source area. Three extraction wells would be installed to a depth of 45 feet bgs into the shallow bedrock aquifer along the downgradient (west) end of the ECE property to maximize capture of the highest concentrations of Cr(VI) and reduce the potential for being flushed outside the source area (Figures 7-1 through 7-4). Groundwater would be extracted at a rate of approximately 8 to 10 gpm per well. The extracted water would be treated by ex situ methods such as ion exchange, chemical reduction and precipitation, or bioreactors, before reinjection. For this FS, ion exchange treatment is assumed. Treated groundwater would be reinjected into six upgradient injection wells installed to a depth of 45 feet bgs into the shallow bedrock along the upgradient (east) end of the ECE property (Figures 7-1 through 7-4). Treated extracted groundwater would be reinjected through the injection wells to help flush contaminated groundwater toward the extraction wells, increasing the overall effectiveness of the system. If all the extracted groundwater could not be reinjected, a portion of it would be discharged to a POTW, or to the river under a NJPDES permit. The pump-and-treat system would be operated until diminishing returns on concentration reduction are observed, or until concentrations in the shallow bedrock are reduced below the NJDEP GWQS for total Cr. For this FS, the assumed operation timeframe of the source area pump-and-treat system is 6 years.

In Situ reduction, in combination with pump and treat, would be used to treat the shallow bedrock within the source area. The reduction would convert Cr(VI) to Cr(III), which would precipitate out of solution and remain in the subsurface. One possible approach would be to amend extracted groundwater with a reductant (such as EVO, sodium lactate, or CaSx), and reinject the amended groundwater into the upgradient injection wells to develop an in situ reduction zone across the entire source. Amended groundwater would be reinjected through permanent wells, based on the recommendations from the Pilot Study (Section 2.2.3). Use of EVO as a reductant, will be assumed for alternative evaluation in this FS. A pH buffer is not considered under this alternative, based on pH neutralizing capacity of calcite in the shallow bedrock. Based on the dosing recommendations from the pilot study (Section 2.2.3) an estimated 33,938 pounds of EVO (60 percent by weight solution) would be injected every 3 years for the first 6 years. The operation timeframe of the source area in situ reduction is assumed to be 6 years. During this timeframe, the pump-and-treat system may be operated intermittently to optimize distribution of EVO across the source area without extracting amended groundwater.

To provide monitoring within the shallow bedrock within the ECE property boundary, four new permanent monitoring wells would be installed to a depth of 45 feet bgs. The wells would be monitored to assess concentration trends, establishment of reducing conditions across the source area, and overall performance of the remedy.

Monitoring would be performed within the existing downgradient plume well network to evaluate the fate of the plume after the source has been treated. Quarterly monitoring would be conducted for Cr(VI) and redox indicator parameters for the first 5 years and would be assumed to be reduced to annual monitoring thereafter and continued for up to 30 years, for cost estimating purposes. ICs would also be implemented to reduce the risk of ingesting contaminated groundwater

Additionally, ongoing basement investigations and remedial actions including decontamination, the application of sealants, and/or the installation of drainage trenches and sumps would be carried out in areas that continue to be impacted by elevated concentrations of Cr(VI) in groundwater. For this FS, it is assumed that five basements will be inspected per year, with remedial actions being implemented at two basements per year. The remedial action assumptions include decontaminating and applying sealant at one location and decontaminating, plus installing a French drain at the second location. This process would be carried out over 20 years.

7.2.3 Alternative 3: Source Treatment and In Situ Reduction Barriers for Overburden

Under this alternative, one of the two source treatment alternatives as described in Alternative 2 would be implemented.

Overburden plume treatment would also be implemented with a series of in situ reduction barriers arranged perpendicular to the flow of the overburden plume, as depicted conceptually in Figure 7-5.

The reduction barriers would be established by injecting a reducing agent into a series of permanent injection wells. The optimal remedial design, including injection well layout and reagent selection, will be developed during the remedial design phase. For the alternative evaluation in this FS, the design parameters included in Table 7-1 and further discussed below will be assumed:

- An estimated 290 permanent injection wells would be installed across 5,800 feet of treatment barrier, spaced on 20-foot centers within the overburden plume. The wells would be installed to the top of the competent bedrock layer, assumed to be 50 feet bgs. Based on the results of the pilot study (Section 2.2.3), permanent injection wells would be used to achieve better radius of influence and to allow for infrastructure for multiple injections. The location of the barriers would be limited to the City of Garfield right-of-way within roadways.
- A variety of reducing amendments, including EVO, sodium lactate, or CaSx, could be used to establish reducing conditions. For this FS and based on the pilot test, EVO is assumed as the reducing amendment to maximize the longevity of the barriers and minimize the frequency of reinjections. A pH buffer is not considered under this alternative, based on neutral pH groundwater in the overburden downgradient of the source area. Based on the dosing recommendations of the pilot study (Section 2.2.3), approximately 1,640,240 pounds of a 60 percent by weight solution of EVO would be injected across the overburden plume every 3 years for the first 10 years, and then on a reduced mass and frequency thereafter as needed to maintain reducing conditions. A UIC permit will be needed to perform injection work. Injections would be carried out until a 90 percent reduction in the aerial footprint of the plume exceeding the NJDEP GWQS for total Cr is achieved. For costing purposes within this FS, the timeframe for in situ barrier injections is assumed to be 30 years.
- To provide monitoring within the overburden plume, six new permanent overburden monitoring wells would be installed throughout the plume to a depth of 50 feet bgs. The wells would be monitored to assess concentration trends, establishment of reducing conditions across the plume area, and overall performance of the remedy.
- Monitoring would be used to manage the lower concentration fringes of the plume, and ICs would be implemented to reduce the risk of ingesting contaminated groundwater. The mobilization of reduced metals (e.g., iron, manganese, and arsenic) in the aquifer will also need to be monitored during implementation of the in situ reduction barriers.
- Additionally, ongoing basement investigations, as described for Alternative 2 would be implemented.

7.2.4 Alternative 4: Source Treatment and Pump and Treat for Overburden

Under Alternative 4, one of the two source treatment alternatives as described in Alternative 2 would be implemented.

An overburden plume pump-and-treat system would also be installed and operated to extract and treat the highest concentrations of Cr(VI) within the plume, as depicted in Figure 7-6. The optimal remedial design, including wellfield design and treatment and disposal process options, will be developed during the remedial design phase. For the alternative evaluation in this FS, the design parameters included in Table 7-1 and further discussed in the following paragraphs will be assumed:

A series of overburden groundwater extraction wells would be installed throughout the core of the plume. For this FS, it is assumed that 14 permanent extraction wells would be installed to the top of competent bedrock at an assumed depth of 50 feet bgs. The location of well installation is limited to the City of Garfield right-of-way on roadways.

Groundwater would be extracted at a rate of approximately 10 gpm per well. The extracted water would be conveyed to a treatment plant constructed at the ECE property to be treated by ex situ methods such as ion exchange, chemical reduction and precipitation, or bioreactors. For this FS, ion exchange treatment is assumed.

Following treatment, extracted groundwater may be partially or fully discharged back into the aquifer, into the POTW sanitary sewer, or into the Passaic River under an NJPDES permit. Reinjection into the subsurface may results in localized mounding of the water table resulting in increased infiltration into basements. Therefore, for this FS, the assumed method of discharge is to the Passaic River under an NJPDES permit.

For costing purposes within this FS, the operation timeframe of the overburden plume pump-and-treat system is assumed to be 30 years. However for the modeling, the pump-and-treat systems were assumed to operate longer, as discussed in Section 7.5.2.

To provide monitoring within the overburden plume, six new permanent monitoring wells would be installed to the top of the competent bedrock, which is assumed to be 50 feet bgs. The wells would be monitored to assess concentration trends and long-term fluctuations in the water table because of extraction and overall performance of the remedy.

Monitoring would be used to manage the lower concentration fringes of the plume, and ICs would be implemented to reduce the risk of ingesting contaminated groundwater. Additionally, basement remediation as described in Alternative 2 will be implemented.

7.2.5 Alternative 5: Source Treatment and Combined Pump and Treat and In Situ Reduction for Overburden

Under Alternative 5, one of the two source treatment alternatives as described in Alternative 2 would be implemented.

A combination of the overburden plume remedy components described in Alternative 3 (in situ reduction barriers) and Alternative 4 (pump and treat) would also be implemented to combine Cr(VI) mass removal and containment with in situ treatment, as depicted conceptually in Figure 7-7. The optimal remedial design, including wellfield design, treatment and disposal process options, and reagent selection, will be developed during the remedial design phase. For the alternative evaluation in this FS, the design parameters included in Table 7-1 and described in Sections 7.2.3 and 7.2.4 will be assumed. For this FS, the assumed operation timeframe of the overburden plume pump-and-treat system and in situ barrier injections are both 30 years.

Monitoring, ICs, and basement remediation described in Alternative 2 would also be implemented under Alternative 3.

7.3 Evaluation Process and Criteria

The NCP defines nine criteria—classified as threshold, balancing, or modifying—to be used for the evaluation and analysis of remedial alternatives. The definitions of these criteria from the USEPA RI/FS guidance (USEPA 1988a) are presented below and summarized in Table 7-2.

The detailed analysis is performed using a two-step process. During the first step, each alternative is evaluated individually against the NCP criteria and the sustainability/green remediation metrics. In the second step, a comparative analysis is performed using the same criteria to identify key differences between alternatives. The detailed analysis presents the significant components of each alternative, the assumptions used, and the uncertainties associated with the assessment.

7.3.1 NCP Threshold Criteria

To be eligible for selection, an alternative must meet the threshold criteria described below, or in the case of compliance with ARARs, a waiver, if necessary, must be justified.

7.3.1.1 Overall Protection of Human Health and the Environment

This criterion evaluates whether an alternative can protect human health and the environment. This criterion draws on the analyses performed for other evaluation criteria, particularly long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs. Evaluation of overall protection of human health and the environment offered by each alternative focuses on the following:

- Determining whether an alternative achieves adequate protection
- Considering how site risks associated with each exposure pathway are either eliminated, reduced, or controlled through treatment, engineering, or ICs
- Determining if an alternative will result in any unacceptable short-term or cross-media effects

7.3.1.2 Compliance with ARARs

This evaluation criterion is used to determine whether an alternative meets the substantive portions of the federal and state ARARs defined in Section 4 and in Tables 4-1 and 4-2. It must be noted that under CERCLA, permits are not required for actions conducted onsite; however, the substantive requirements of the associated ARARs must be met.

CERCLA authorizes the waiver of an ARAR with respect to a remedial alternative if any of the following bases exist (USEPA 1988a):

- The alternative is an interim measure that will become part of a total remedial action that will attain the ARAR.
- Compliance with the requirement will result in greater risk to human health and the environment than other alternatives.
- Compliance with the requirement is technically impracticable from an engineering perspective.
- The alternative will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, or limitation through use of another method.

With respect to a state requirement, the state has not consistently applied, or demonstrated the intention to consistently apply, the promulgated requirement in similar circumstances at other remedial actions within the state.

7.3.2 NCP Balancing Criteria

Alternatives meeting the threshold criteria are further evaluated using the five primary balancing criteria described in the following subsections.

7.3.2.1 Long-Term Effectiveness and Permanence

The assessment against this criterion evaluates the long-term effectiveness of the alternatives in maintaining consistent protection of human health and the environment after the RAOs have been met. A key component of this evaluation is to consider the extent and effectiveness of controls that may be required to manage risk posed by treatment residuals and/or untreated waste. The long-term effectiveness of an alternative is assessed by considering the following two factors:

- **Magnitude of residual risk** assesses the residual risk remaining from untreated waste or treatment residuals at the conclusion of the remedial activities.

- **Adequacy and reliability of controls** evaluates the capability and suitability of controls, if any, that are used to manage treatment residuals or untreated wastes that remain at the site.

7.3.2.2 Reduction of Toxicity, Mobility, or Volume through Treatment

This evaluation criterion addresses the statutory preference for selecting remedial actions that employ treatment technologies resulting in the permanent and significant reductions of toxicity, mobility, or volume (TMV) of the hazardous substances as their principal element. This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, irreversible reduction in contaminant mobility, or reduction of total volume of contaminated media. The following six factors are considered when evaluating alternatives against this criterion:

- The treatment processes the remedy will employ and the materials they will treat.
- The amount of hazardous materials that will be destroyed or treated (including how the principal threat(s) will be addressed).
- The degree of expected reduction in TMV measured as a percentage of reduction (order of magnitude).
- The degree to which the treatment is irreversible.
- The type and quantity of treatment residuals remaining following treatment.
- Whether the alternative satisfies the statutory preference for treatment as a principal element.

Of particular importance in evaluating this criterion is the assessment of whether treatment is used to reduce principal threats, including the extent to which TMV is reduced either alone or in combination.

7.3.2.3 Short-Term Effectiveness

This criterion assesses the effects of the alternative during its construction and implementation until the RAOs are met. Alternatives are evaluated with respect to their effects on human health and the environment during their implementation. The following factors are considered when evaluating alternatives against this criterion:

- **Protection of the community during remedial actions** addresses any risk resulting from the remedy implementation. Examples include dust from excavations, transportation of hazardous materials, and air-quality impacts.
- **Protection of workers during remedial actions** assesses threats potentially posed to workers and the effectiveness and reliability of protective measures that would need to be taken.
- **Environmental impacts** considers the environmental impacts potentially resulting from the construction and implementation of the alternative and assesses the reliability of available mitigation measures for preventing or reducing those impacts.
- **Time until RAOs are achieved** includes an estimate of the time required to achieve protection for either the entire site or individual elements associated with specific site areas or threats.

7.3.2.4 Implementability

The implementability criterion assesses the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during the remedy implementation. The following factors are considered when evaluating alternatives against this criterion:

- **Technical feasibility** includes the following:
  - **Construction and operation** relates to the technical difficulties and unknowns associated with a technology.

  - **Reliability of technology** focuses on the likelihood that technical problems associated with the implementation will result in schedule delays.
  - **Ease of undertaking additional remedial action** includes a discussion of what, if any, future remedial actions may need to be performed and how difficult it would be to implement those actions.
  - **Monitoring considerations** addresses the ability to monitor the effectiveness of the remedy and includes an evaluation of exposure risk should monitoring be insufficient to detect a failure.
- **Administrative feasibility** assesses the activities required to coordinate with other offices and agencies (such as access, right-of-way).
- **Availability of services and materials includes an evaluation of the availability of appropriate offsite treatment, storage capacity, and disposal services**; necessary equipment and specialists; services and materials (including the potential for competitive bidding); and the availability of prospective technologies.

7.3.2.5 Cost

This criterion includes all the engineering, construction, and operations and maintenance (O&M) costs incurred over the life of the project. The evaluation of cost includes three principal components:

- **Capital costs** includes direct (construction) and indirect (nonconstruction and overhead) costs. Equipment, labor, and materials required for the installation of the remedy are considered direct costs. Indirect costs consist of those expenses related to the engineering, financial, and other services that are necessary to complete the remedy installation but are not part of the actual installation or construction activities.
- **Annual O&M costs** refers to post-construction expenditures required to ensure continued effectiveness of the remedial action. Components of annual O&M costs include auxiliary materials, monitoring expenses, equipment or material replacement, and 5-year review reporting.
- **Present worth analysis** is a method of evaluating expenditures such as construction and O&M that occur over different lengths of time. This allows costs for remedial alternatives to be compared by discounting all costs to the year that the alternative is implemented. The present worth of a project represents the amount of money, which if invested in the initial year of the remedy and disbursed as needed, would be sufficient to cover all costs associated with the remedial action.

The level of detail required to analyze each alternative with respect to the cost criteria depends on the nature and complexity of the site, the types of technologies and alternatives being considered, and other project-specific considerations. The analysis is conducted in sufficient detail to understand the significant aspects of each alternative and to identify the uncertainties associated with the evaluation.

The cost estimates presented for each alternative have been developed for the purpose of comparing the alternatives. The final costs of the selected remedy will depend on actual labor and material costs, competitive market conditions, final project scope, the implementation schedule, and other variables. The cost estimates are order-of-magnitude estimates with an intended accuracy range of plus 50 to minus 30 percent. The range applies only to the alternatives as they are described in this report and does not account for changes in the scope of the alternatives. Selection of specific technologies or processes to configure remedial alternatives is not intended to limit flexibility during remedial design but to provide a basis for preparing cost estimates. The specific details of the selected remedial alternative and the corresponding cost estimate need to be refined during the final remedial design.

7.3.3 NCP Modifying Criteria

The two modifying criteria are state acceptance and community acceptance. The evaluation of these criteria is typically not completed until state and public comments are received on the proposed plan.

7.4 Detailed Analysis of Alternatives

7.4.1 Remedial Alternative Modeling

A numerical model of the site was built using the groundwater flow and solute transport modeling software MODFLOW-SURFACT (HydroGeoLogic 1996). The numerical model was carried out in two phases, as detailed in the *Garfield Groundwater Contamination Superfund Site Phase 1 Groundwater Flow Modeling Technical Memorandum* (CH2M 2014c) and the *Garfield Groundwater Contamination Superfund Site Phase 2 Solute Transport Modeling Technical Memorandum* (CH2M 2015b) included in Appendix C.

7.4.1.1 Phase 1

Phase 1 consisted of building and calibrating a groundwater flow model, representing five separate stratigraphic layers (overburden, weathered bedrock, and three layers of bedrock) over an area of 3.3 square miles, with 50-foot grid spacing (CH2M 2014c). General head boundary conditions were setup on the eastern and western boundaries of the plume, no flow boundaries were setup on the northern and southern boundaries of the plume, and the Passaic River was implemented as a boundary condition in the overburden layer. Natural groundwater flow in the model is toward the Passaic River, which is consider the lowest point of hydraulic head. The river is thus the discharge point for all overburden groundwater in the model domain. A recharge rate of 8 inches per year, based on regional rainfall data, was incorporated at the upgradient boundary. The Phase 1 modeling efforts are detailed in the *Garfield Groundwater Contamination Superfund Site Phase 1 Groundwater Flow Modeling Technical Memorandum* (CH2M 2014c), included in Appendix C.

The GFM provided the basis for the CTM built during Phase 2. The CTM used the same model grid layout, boundary conditions, and hydraulic properties as the GFM. To provide more vertical resolution for defining the Cr plume, the upper bedrock layer (Model Layer 3 from the GFM) was divided into two layers in the CTM. The average layer thicknesses in the CTM were as follows:

- Overburden—49 feet
- Weathered Bedrock—19 feet
- Upper Bedrock—50 feet
- Upper Middle Bedrock—50 feet
- Middle Bedrock—100 feet
- Lower Bedrock—277 feet

7.4.1.2 Phase 2

Phase 2 consisted of building a CTM for Cr(VI), but incorporating the flow model from Phase 1 to determine groundwater flow velocities and calculate contaminant migration through the flow field. Following development of the CTM, the remedial alternatives for the overburden plume, described in Section 7.2, were modeled to forecast their potential remediation timeframes (RTFs).

The Phase 2 model used a dual-domain transport simulation, with a mobile domain modeled by well-connected pores (or fractures) and contaminant transport dominated by advection, and an immobile domain modeled by poorly connected pores (such as rock matrix) and contaminant transport dominated by diffusion. Contaminant exchange between the two domains takes place solely via diffusion. The dual domain allowed for the accurate modeling of immobile Cr(VI) contained within the rock matrix, and the influence that rebound from this immobile mass had during implementation of remedial actions. In model simulations, the rate of this diffusive mass transfer is governed by a mass transfer coefficient. The mass transfer coefficient is not easily measured in the field, and varies according to the age of the plume. The mass transfer coefficient is also affected by the degree of proximity or "average distance" between the mobile and immobile domains. The overburden mass transfer coefficient selected for the model was 4.4e-5 day^{-1}, based on the assumption that the plume has been present since late 1952.

Cr(VI) concentrations, collected from 84 wells during the most recent groundwater sampling event (December 2014, Figures 2-4 and 2-5) were used to develop the Phase 2 model. The groundwater concentrations were incorporated in the mobile domain and were used to develop the immobile domain concentrations, based on an assumed established equilibrium within the plume over time. Concentrations within the ECE property were calculated based on estimates of the Cr(VI) mass remaining following the 2014 excavations. This estimated source Cr(VI) mass includes 53 kilograms in the overburden groundwater and 1,328 kilograms in the overburden soil. From these mass estimates, the volume of the overburden groundwater and soil, and assumed distribution properties, a source area initial mobile phase concentration was estimated to be 60,000 µg/L. The source area immobile phase was initialized to 351,300 µg/L to be consistent with the estimate of Cr(VI) mass remaining there. For Alternatives 2 through 5, which incorporate active source area treatment, Cr(VI) concentrations were modeled at 0 µg/L within the ECE property boundaries.

The sorption of anionic Cr(VI) was considered likely to be minor, so a low sorption coefficient value of 0.05 L/kg was assigned. This equates to retardation coefficients of 1.2 in the overburden and 1.5 in the weathered bedrock. The overburden total porosity was estimated in the RI to be 35 percent (0.35) (CH2M 2014a, Section 4.7). A mobile porosity value of 8 percent was selected as an approximate median of the overburden at the site, which is described in the RI to consist of coarse silty sands, well-graded fine to coarse sand, common gravel stringers, and discontinuous silt and clay units. The resulting immobile porosity was 27 percent (35 minus 8). The weathered bedrock mobile and immobile porosities were assumed to be 0.01 and 0.2, respectively. The longitudinal dispersivity of Cr(VI) at the site was estimated to be 39.2 feet, with transverse and vertical dispersivity being 10 percent of that value (3.92 feet). A diffusion coefficient of 0.0013 square feet per day was assumed. It was assumed that there was no natural degradation of Cr(VI) in the aquifer.

Degradation was added to the CTM simulation along the in situ reduction barriers. An average of 80 percent removal across each barrier was assumed, to be conservative. To achieve the 80 percent removal, degradation rates in the model cells representing each barrier were adjusted iteratively until the desired 80 percent decrease was (approximately) achieved in the model cells immediately downgradient from the barriers.

The Phase 2 modeling efforts are detailed in the *Garfield Groundwater Contamination Superfund Site Phase 2 Solute Transport Modeling Technical Memorandum* (CH2M 2015b), which is included in Appendix C.

7.4.1.3 Remedial Time Frame Estimation

RTFs for each alternative were developed once the CTM was completed. RTFs estimated from the CTM were based on both a 90 percent reduction in the overall plume area and reduction of Cr(VI) concentrations to below the New Jersey GWQS for total Cr. RTFs are provided in Table 7-3, and Figure 7-8 depicts model-projected progress for each alternative over time. Graphics presenting the Cr(VI) remediation progress over time for each alternative are also included in Appendix C (Figures C-12 through C-16).

Model results predict that RTFs to achieve 90 percent reduction of the plume area could be greater than a century for four of the five alternatives. Complete Cr(VI) concentration reduction to below the New Jersey GWQS for total Cr is not predicted to be achieved by any of the alternatives in under 140 years. As shown in Figure 7-8, active treatment, including just the source area in Alternative 2, results in a significant reduction in RTF as compared to no further action under Alternative 1.

Modeling also predicts that once New Jersey GWQS for total Cr are met and active treatment is completed, rebound from untreated Cr(VI) in the immobile zones will lead to recontamination of the overburden aquifer. Modeling also suggests that the more aggressive alternatives with shorter RTFs would also experience the greatest degree of rebound. Graphics presenting the expected overburden aquifer rebound following system shutdown for each alternative are included in Appendix C (Figure C-29).

As discussed in more detail in Appendix C, the RTF predictions are sensitive to the mass transfer coefficient, which is not easily measured in the field and must be estimated based on assumptions of the plume history. As such, there is a high level of uncertainty in the RTF predictions. For example, a reduction in mass transfer coefficient from 4.4e-5 days^{-1} to 1.1e-5 days^{-1} results in a remediation timeframe that is nearly twice as long. The changes in remediation timeframe from increasing the mass transfer coefficient are not quite as dramatic. A four-fold increase in the mass transfer coefficient results in a remediation timeframe reduction by less than one half.

There is a high level of uncertainty in the RTF predictions due the large effect that Cr(VI) mass transfer rates between the mobile and immobile domain have on remedial timeframe projections. As an ionic solute with relatively small molecular weight, Cr(VI) readily diffuses into the immobile domain. The plume at Garfield is many decades old, so there has been sufficient time for diffusion to occur. Therefore, while it is not possible to measure or predict the precise rate of mass transfer or the relative mass fraction present in the immobile domain, it would be reasonable to assume that the mass of Cr(VI)-in the immobile domain is significant and that back diffusion will significantly affect the remediation timeframes at this site. As part of the sensitivity analysis, a simulation was conducted assuming no mobile domain was present. This simulation is not considered to represent a reasonable projection of remedial timeframe at this site, but rather to provide a demonstration of the large effect that the immobile domain has on the remedial timeframe projections and therefore the relatively large degree of uncertainty that is inherent in the those projections.

7.4.2 Alternatives Analysis against NCP Criteria

The objective of the detailed analysis of alternatives is to provide adequate information for each alternative to facilitate the selection of remedial actions for implementation at the site. Each alternative was assessed under the evaluation criteria specified in the NCP (Section 7.3). The detailed analysis consisted of an individual evaluation of each alternative in relation to the two "threshold criteria" and five "balancing criteria". The two modifying criteria will be assessed following completion of this FS in the responsiveness summary to the Proposed Plan.

The detailed analysis for each individual alternative (1 through 5) against the NCP criteria is presented in Table 7-4. Based on the findings of the individual alternative analysis, all four alternatives will be carried forward to the comparative analysis presented in Section 7.5.

The relative cost rankings for the alternatives were developed based on an assumed 30-year timeframe, in accordance with CERCLA guidance for costing procedures. The actual duration of the proposed remedies would be based on monitoring results and are expected to exceed the 30-year timeframe. The cost evaluations were presented for the 30-year timeframe in this FS for consistency between alternatives. Costs were prepared to include all engineering, construction, and O&M costs that will be incurred over the life of the project. Costs were developed to reflect an accuracy of +50/-30 percent. Costs comparisons for each alternative are included in Table 7-5, and breakdowns for each alternative are included in Appendix D.

7.4.3 Sustainability Evaluation

The USEPA OSWER and USEPA Region 2, have a goal to implement sustainable and/or green practices as part of remedial actions, where practicable. The OSWER Technology Primer titled *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (USEPA 2008) cites the following six core elements of green remediation:

- Energy requirements of the treatment system
- Air emissions

- Water requirements and impacts on water resources
- Land and ecosystem impacts
- Material consumption and waste generation
- Long-term stewardship actions

Similarly, USEPA Region 2 has implemented a “Clean & Green” Policy that establishes a preference for the following (USEPA 2010b):

- One-hundred percent use of renewable energy, and energy conservation and efficiency approaches, including EnergyStar equipment
- Cleaner fuels and clean diesel technologies and strategies
- Water conservation and efficiency approaches, including WaterSense products
- Sustainable site design
- Industrial material reuse or recycling within regulatory requirements
- Recycling applications for materials generated at or removed from the site
- Environmentally preferable purchasing
- Greenhouse gas (GHG) emission reduction technologies

The USEPA OSWER has also prepared best management practices for frequently used cleanup remedies, various field stages, and other aspects posing significant opportunities to reduce the environmental “footprint” of site cleanup (USEPA 2014b). Best management practices relevant to the alternatives evaluated in this FS include the following:

- Pump and Treat Technologies
- Bioremediation
- Materials and Waste Management
- Overview of USEPA’s Methodology to Address the Environmental Footprint of Site Cleanup

These items will be considered during preparation of the detailed design of the selected remedy.

Although sustainability is not one of the nine NCP criteria, each alternative was qualitatively assessed from a sustainability standpoint, following the guidelines listed above.

Alternative 1, no further action, is considered sustainable since under this alternative no further actions would be carried out onsite, and therefore impacts related to energy use, GHG emissions, use of materials and resources, and impacts to land and ecosystems would be minimized. However, it should be noted that under the no further action alternative, water resources would not be protected because of untreated and unmonitored groundwater contamination, and therefore, the alternative cannot be considered sustainable from an impacts to water resources stand point.

Under Alternatives 2, 3, 4, and 5, basement remediation is considered sustainable. For source zone treatment (assuming the scope under Alternative 2A), the soil mixing is considered moderately sustainable because it is an energy intensive process requiring the use of heavy machinery. The use of heavy machinery would increase air emission and have negative impacts on GHG emissions over a short time period. Additionally, soil mixing would disturb the land on the ECE property temporarily, but could be graded and vegetated following soil mixing for sustainable reuse of the land. For source zone treatment (assuming the scope under Alternative 2B), in situ injections are also considered sustainable to moderately sustainable, due to the limited use of heavy machinery to install injections wells, and limited disruption to the surrounding community during delivery and injection of the reducing agents over 6 years.

Under Alternatives 3 and 5, the implementation of in situ reduction injections is considered poorly to moderately sustainable. From an installation perspective, the in situ reduction barriers would require the use of heavy machinery during the installation of 290 injection wells. The use of heavy machinery would increase air emission and have negative impacts on GHG emissions over a short time period. Delivery and injection of the reducing agents would cause moderate disruption to the surrounding community, but would only be carried out periodically (every 3 to 5 years) if a slow-release substrate like EVO is used. The manufacturing and transport of reducing agents would require large amounts of energy, the use of nonrenewable chemicals, and would contribute to GHG emissions. The use of a reducing agent, produced as a byproduct from other industrial processes would be considered as a viable option to support limiting waste generation. Additionally, the use of EVO to facilitate biological reduction, versus a chemical reductant, is considered a more sustainable option because fewer injection events would need to be performed. During injection activities large amounts of water would be required to carry out the injections; however, reusing treated groundwater under Alternative 5 would reduce the amount of water needed.

Under Alternatives 4 and 5, the implementation of the pump-and-treat system is also considered a poorly to moderately sustainable option. From an installation perspective, the use of heavy equipment would be limited based on the number of wells and length of conveyance piping to be installed, and therefore energy use and GHG emissions would be limited. The operation of the system would require continual ongoing energy use and possible disruption to the surrounding community during the delivery and pickup and treatment equipment, such as ion exchange resin. Alternative forms of energy, such as solar power or wind would be considered when installing the system. By reinjecting or discharging treated groundwater to surface water, there would be little impact on water resources. Assuming an ion exchange system is used for treatment, resins would have to be replaced periodically and transport would increase GHG emissions. Over the duration of the pump-and-treat systems operation, ongoing maintenance would result in the production of used oil, replacement of parts, and reduced efficiencies of equipment, increasing energy consumption, waste produced, and GHG emissions.

Since Alternative 2 does not have an active, long-term component for the overburden plume, it could be considered a more sustainable alternative then those with active treatment in the overburden (Alternatives 3 through 5).

7.5 Comparative Analysis of Alternatives

The comparative analysis of alternatives evaluates the relative performance of each alternative for each of the seven evaluation criteria. The subcriteria within each of the seven NCP criteria were considered during the detailed and comparative evaluation; however, the following discussion focuses on the ranking of the alternatives with respect to the primary criteria. A summary of the five alternatives as they compare individually to the seven NCP criteria is presented in Table 7-4. A comparison of the alternatives for each of the evaluation criteria is provided in the following subsections.

7.5.1 Overall Protection of Human Health and the Environment

Alternative 1, No Action, would not provide overall protection of human health and the environment. This alternative would not achieve the RAOs for the source area or overburden plume within a reasonable timeframe. Contaminated soils would remain within the ECE property boundaries, and groundwater monitoring would not be performed to track plume migration and growth. Potential exposure to groundwater through basement infiltration and future use of the aquifer, along with contact to soils on the ECE property, would continue to pose human health risks.

Alternatives 2, 3, 4, and 5 are expected to be protective of human health and the environment. These alternatives would meet the RAOs by treating source area soils and groundwater, and by implementing the basement remedies and ICs in the overburden plume. By implementing source zone treatment on the ECE property, each of the alternatives would target and treat the highest Cr(VI) concentrations in the overburden and shallow bedrock groundwater. Additionally, by implementing the basement remedies, health risks associated with groundwater infiltration into basements would be mitigated. These alternatives all result in decreases in concentration within the plume, which also would reduce the risk associated with groundwater infiltration into basements. The use of ICs would mitigate potential risks from exposure to groundwater through pathway elimination. In the short term, only RAOs 3 and 4 would be achieved, by implementing basement remedies. Overburden plume treatment to achieve RAOs 1 and 2 are expected to be carried out over a much longer period.

7.5.2 Compliance with ARARs

Under Alternative 1, No Action, no cleanup measures will be taken, and ARARs will not be achieved in a reasonable timeframe. Modeling suggests that achieving groundwater PRG of 70 µg/L in the overburden groundwater plume would take 270 years, as shown in Table 7-3, Figure 7-8, and Appendix C (Figure C-12).

Under Alternatives 2, 3, 4, and 5, chemical-specific ARARs, defined by the PRGs, would be achieved. PRGs in groundwater are expected to be achieved within 1 to 6 years of implementing the source zone treatment, which is a potential component of the four alternatives. Although groundwater PRGs for the overburden plume will be achieved under all four alternatives, the timeframes to achieve the PRGs everywhere are estimated by the model to be long: 220, 177, 174, and 144 years for Alternatives 2, 3, 4 and 5, respectively, as shown in Table 7-3, Figure 7-8, and Appendix C (Figures C-13 through C-16). Monitoring and ICs would be implemented under the four Alternatives until PRGs in groundwater are achieved.

7.5.3 Long-Term Effectiveness and Permanence

The proposed source zone treatment, which is consistent in Alternatives 2, 3, 4, and 5, would be effective and permanently treats Cr(VI) mass within the source area on the ECE property. Once Cr(VI) has been reduced to Cr(III), very little Cr(III) should re-oxidize back to Cr(VI) and total Cr concentrations will remain below ARARs over time.

The MODFLOW model results for the overburden plume indicate treatment of the overburden plume through any four of the proposed alternatives would eventually result in long-term, permanent reduction in dissolved phase Cr(VI) concentrations in the overburden plume, as shown on Figure 7-8 and in the groundwater modeling results included in Appendix C (Figures C-13 though C-16). Alternative 2 achieves the PRGs primarily by dilution and dispersion as the Cr(VI) plume migrates downgradient. Under Alternatives 3 and 5, in situ reduction injections would achieve PRGs by permanently reducing Cr(VI) to Cr(III) in the overburden plume. Under Alternatives 4 and 5, the pump-and-treat system would achieve PRGs by extracting groundwater and providing treatment ex situ.

After the RAOs have been achieved, the four alternatives will likely experience rebound of Cr(VI) concentrations because of untreated Cr(VI) in poorly connected pores and immobile zones, as shown in Appendix C (Figure C-29). Based on modeling results, the alternatives with quicker cleanup timeframes may experience more aggressive rebound.

Alternatives 2, 3, 4, and 5 would all rely on long-term monitoring to evaluate the effectiveness of the implemented remedy. Basement monitoring would be implemented until RAOs are achieved, and ICs would be used to mitigate risks until long-term effectiveness is achieved.

7.5.4 Reduction of Toxicity, Mobility, or Volume through Treatment

In Situ reduction would result in a reduction in both the toxicity and mobility of Cr(VI) by reducing Cr(VI) to Cr(III), which should be permanent. Under Alternatives 2, 3, 4, and 5, toxicity and mobility reduction through in situ reduction is achieved through source treatment.

For Alternative 2, there is no reduction of TMV in the overburden plume through active treatment. Reduction in toxicity and volume of the plume is achieved primarily through dilution and dispersion as groundwater flows downgradient. Under Alternatives 3 and 5, reduction of toxicity and mobility is achieved in the overburden plume through in situ barrier treatment. Overburden plume pump and treat under Alternatives 4 and 5 would result in a reduction in both the toxicity and volume by decreasing Cr(VI) concentrations and by shrinking the overall size of the plume. Based on the selected ex situ treatment, Cr(VI) would either be reduced in volume by being concentrated on in a ion exchange vessel, or reduced in toxicity by chemical treatment.

Of the three alternatives, Alternative 5 which includes both overburden plume pump and treat and in situ barrier treatment would likely be the most effective in TMV reduction since Cr is reduced and removed from the aquifer.

7.5.5 Short-Term Effectiveness

Under Alternatives 2, 3, 4, and 5, the implementation of source zone treatment could be carried out rapidly and be effective in the short term. The source area property is readily accessible and located in a mixed use industrial/residential neighborhood. Local contractors are familiar with the type of work to be carried out and materials are readily available. Soil mixing and in situ injections in the source overburden may result in exposure to harmful chemicals, based on the reducing agent chosen. Soil mixing could be implemented within one year and would begin providing source zone treatment within 1 year of installation. However, soil mixing activities would generate a higher degree of noise and dust impacting nearby residents, compared to in situ injections. In Situ injections would remediate source area overburden, but may require multiple injections over approximately 6 years due to uneven reagent distribution

Alternative 2 would have the least impact on the community or risk to workers, since no active remediation would be implemented in the plume. During implementation, Alternative 2A would have a greater impact on the community than Alternative 2B due to the use of multiple pieces of equipment needed to implement soil mixing. Additionally, the implementation time needed to carry our soil mixing would result in an extended period of disruption to the community as opposed to the installation of wells for injections. The risk of exposure to workers is greater under Alternative 2A, based on the process involved with soil mixing in which contaminated soils are brought to the surface and handled. Under Alternative 2A more chemicals would need to be transported and stored onsite at one time; however, under Alternative 2B, chemicals would need to be transported multiple times over the course of 6 years.

Alternatives 3 and 5 include installing a large injection network throughout the surrounding community. The drilling of wells can be carried out by local contractors, and material can be obtained easily. However, because well drilling is restricted to the City of Garfield right-of-way, traffic may be disrupted for a long period. Additionally, during injections, large quantities of substrate will have to be transported, stored, and handled onsite. Treatment of the overburden plume will not begin until injections are completed and reducing conditions are established within the aquifer. The mobilization of reduced metals (e.g., iron, manganese, and arsenic) in the aquifer will need to be considered and monitored during implementation of the in situ reduction barriers.

The overburden plume pump-and-treat system under Alternative 4 would take less time to implement and cause less impact on the surrounding community than establishing in situ barriers. The effectiveness of the pump-and-treat system under Alternative 5 would be restricted by the time needed to install the in situ barriers, and therefore, would have similar short‑term effectiveness as Alternative 3. Once implemented, the pump-and-treat systems under Alternatives 4 and 5 would provide immediate treatment of Cr(VI).

The MODFLOW model results for the overburden plume indicate treatment of the overburden plume through any four of the alternatives would not result in short-term reduction in plume size, and thus a reduction in the number of basements with potential exposure risk. A 90 percent reduction in overburden plume area is estimated to take 180, 111, 117, and 84 years, under Alternatives 2, 3, 4, and 5, respectively, as shown in Table 7-3, Figure 7-8, and Appendix C (Figures C-13 through C-16).

The time to achieve RAOs 3 and 4 would be the same for Alternatives 2, 3, 4, or 5, since the RAOs would be largely met through the basement inspections and remediation.

7.5.6 Implementability

The source remediation component of all alternatives could readily be implemented using commonly available technologies and local contractors. Implementation of the source area remedy would generally be feasible because all aboveground structures have been removed; however, soil mixing may be constrained due to the limited space within the ECE property and site traffic control issues.

Alternative 2 would be easier to implement than Alternatives 3, 4, or 5, since it does not involve active remediation in the overburden plume. The presence of the overburden plume beneath the highly urbanized and densely populated city areas and the abundance of utilities in the streets pose severe constraints on performing groundwater remediation under Alternatives 3, 4, and 5. Alternatives 3 and 5 would result in heavier disturbance of the community during plume remedy implementation because of the large number of injections wells required. Because of the number of wells, implementation time of the system is expected to be longer than Alternatives 2 or 4. Additionally, large volumes of substrate to facilitate the injections would need to be transported and stored onsite. Permits needed to carry out the plume injections under Alternatives 3 and 5 include a UIC for injections and right-of-way permits during well installation and injections. Right-of-way permits would also be required under Alternatives 4 and 5 for installing extraction wells. Permits necessary under Alternatives 4 and 5 for discharge of treated groundwater may include NJPDES, UIC, or POTW permits.

Alternatives 4 and 5 would require continued O&M of the pump-and-treat systems over a long period. This may require operator attention at least weekly. Alternative 3 would only require attention every 3 years when substrate would be reinjected.

7.5.7 Costs

A summary of the estimated cost for each alternative is provided in Table 7-5, broken out by capital costs, O&M costs, and total costs. For the purposes of cost estimating, soil mixing was assumed as the overburden source treatment option for Alternatives 3, 4, and 5. Appendix D presents the detailed cost estimates and associated assumptions. USEPA's *Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (USEPA 2000b) was followed in the setup of these cost estimates. Scope and bid contingencies, as well as design and project management costs, were added in accordance with this guidance. The estimated accuracy of the costs is -30 percent to +50 percent and a discount rate of 7 percent was applied to calculate present value costs in accordance with USEPA guidance. For costing purposes, each alternative has an estimated duration of 30 years, although it is anticipated that contaminant concentrations will exceed ARARs for much longer periods.

Alternative 2 (both soil mixing and in situ injection options) has the lowest capital and O&M costs, since it does not include active remediation of the plume.

Alternatives 3 and 5 have the highest capital costs, primarily because of the installation of the large number of injection wells and EVO injections every 3 years. They also have higher O&M costs compared to Alternative 4, because of the high cost of reinjection of substrate.

7.6 Remedial Design Considerations

The evaluations performed in this FS have identified a number of elements that may require further consideration during the remedial design. The evaluations and analyses listed below are not prescriptive or complete, but simply summarize possible data collection activities identified during the development and analysis of alternatives.

During the remedial design process for the source area treatment, a number of bench scale tests would need to be performed to help finalize the design. Bench-scale testing would be performed on saturated soils at the site to help determine the most effective reducing agent and dosage needed during overburden soil mixing or injection activities. Additionally, based on the results of the ECE property pilot test, pH buffering may be needed for in situ reduction within the source zone. Bench-scale tests would be carried out to determine an appropriate buffering agent and dosage as well as reducing agent needed to achieve and retain reducing conditions in the source area.

During the remedial design process for the overburden aquifer pump-and-treat system, pump tests in the overburden may be carried out to determine pumping rates. The tests may be performed in various locations across the site and the results used with the model to help finalize the well configuration. Discussions would be held with the City of Garfield to help determine piping configurations and location of the water treatment plant. Additionally, an evaluation of ex situ treatment processes would be conducted to help design and configure the treatment plant for extracted groundwater. Discussions with the local regulatory agencies regarding the discharge location of treated groundwater would be initiated prior to finalizing a remedial design.

If in situ reduction is chosen as part of the remedial action, then additional pilot tests may be carried out within the overburden plume. The pilot study would help determine injection rates and radius of influence that would be used to finalize the injection well configuration for the final design. Additionally, the pilot study may be used to test the effectiveness of different substrates and determine the need for a pH buffer within the overburden plume. Discussions would be held with the City of Garfield before final design to determine well locations and sequencing of work to reduce impacts to the surrounding community.

The remedial design may also include additional evaluation and analysis of the sustainability impacts of the selected alternative and consider potential ways to reduce the overall environmental footprint of the remedy. Examples include considering approaches to minimize energy and fuel use by reducing transportation distances and using the most efficient form of transportation possible for both supplies (such as in situ reduction substrate), using clean fuel burning equipment during soil mixing and installing wells in the overburden, and maximizing the beneficial use of ex situ treatment processes.

SECTION 8
References

Avatar Environmental. 2015. *Benthic Baseline Ecological Risk Assessment, Garfield Groundwater Contamination Superfund Site, Garfield, Bergen County, NJ.* March.

CH2M HILL (CH2M). 2014a*. Remedial Investigation Report, Garfield Groundwater Contamination Superfund Site.* City of Garfield, Bergen County, New Jersey. April.

CH2M HILL (CH2M). 2014b. *Results of Aquifer Testing, Garfield Groundwater Contamination Superfund Site, New Jersey Technical Memorandum.* April 4.

CH2M HILL (CH2M). 2014c. *Garfield Groundwater Contamination Superfund Site Phase 1 Groundwater Flow Modeling Technical Memorandum.* August.

CH2M HILL (CH2M). 2015a. *Results of the In Situ Reduction Pilot Study, Garfield Groundwater Contamination Superfund Site, New Jersey Technical Memorandum.* August.

CH2M HILL (CH2M). 2015a. *Garfield Groundwater Contamination Superfund Site Phase 2 Solute Transport Modeling Technical Memorandum.* October.

Chapin Engineering. 2009–*Preliminary Assessment Report of E.C. Electroplating, Inc.* June.

Eary, L. Edmond and Dhanpat Rai. 1987. “Kinetics of Chromium(III) Oxidation to Chromium(VI) by Reaction with Manganese Dioxide,” *Environ. Sci. Technol.* 21(12):1187-1193.

Herman, G. C. 2001. “Hydrogeological Framework of Bedrock Aquifers in the Newark Basin, New Jersey.” *Geology in Service to Public Health, Field Guide and Proceedings*. P. La Combe and G. C. Heiman, eds. Annual Meeting of Geological Association of New Jersey.

HydroGeoLogic, Inc. 2008. *MODHMS/MODFLOW-SURFACT, A Comprehensive MODFLOW-Based Hydrologic Modeling System.* April.

Kasenow, M., and P. Pare. 1995. *Using Specific Capacity to Estimate Transmissivity, Field and Computer Methods*. Highlands Ranch, Colorado: Water Resources Publications.

Lewis-Brown, J.C., and Eric Jacobsen. 1995. “Hydrogeology and ground-water flow, fractured Mesozoic structural-basin rocks, Stony Brook, Beden Brook, and Jacobs Creek drainage basins, west-central New Jersey*.” U.S. Geological Survey Water Resources Investigations Report.* 94-4147.

Lockheed Martin Technology Services. 2010. *E.C. Electroplating Inc. Site, Garfield, New Jersey, Work Assignment SERAS-028, Trip Report, Groundwater and Soil Sampling.* November 3.

Michalski, Andrew. 1990. *Hydrogeology of the Brunswick (Passaic) Formation and Implications for Ground Water Monitoring Practice.* National Ground Water Association Journal Groundwater Monitoring & Remediation – Fall 1990 Edition. P. 141.

Morin, R. H., L.A. Senior, and E.R. Decker. 2000. *Fractured-Aquifer Hydrogeology from Geophysical Logs: Brunswick Group and Lockatong Formation, Pennsylvania*.

National Climate Data Center Division of the National Oceanic and Atmospheric Administration. 2013.

New Jersey Department of Environmental Protection (NJDEP). 2007a. Letter from David Morrow/NJDEP to Bennett Barnes, Case Manager/NJDEP. Subject: Howil Corp, ISRA Case #E89364, Garfield, Bergen County. December 21.

New Jersey Department of Environmental Protection (NJDEP). 2007b. Chromium Moratorium: Letter from Lisa Jackson/NJDEP. Subject: Hexavalent Chromium. Clean up standards for antimony, cadmium, and lead followed the J.J.A.C. 7:26D: Remediation Standards, October 3, 2011, NJDEP RDCSRS. February 8.

New Jersey Department of Health and Senior Services (NJDHSS). 2007. Letter from Glen Pulliam/Occupational Health Consultant to Joe Costentino/On Scene Coordinator USEPA. September 26.

Nichols, W.D. 1968. *Ground-Water Resources of Essex County, New Jersey*. Special Report No. 28. P. 1-14.

Olsen, Paul E. 1980. "*The latest Triassic and Early Jurassic formations of the Newark basin (eastern North America, Newark Supergroup): stratigraphy, structure, and correlation*." New Jersey Academy of Science, *The Bulletin*, v. 25, p. 25-51.

Payne, F. C., J. A. Quinnan, and S. T. Potter. 2008. *Remediation Hydraulics*. pp 68-69. Taylor & Francis Group, LLC.

Princeton Aqua Science. 1984. *Report on Site Evaluations*. December.

Raritan Enviro Sciences, Inc. 1995 *Remedial Investigation Report, E.C. Electroplating, Garfield, New Jersey*. August 17.

Raritan Enviro Sciences, Inc. (RES). 1997. *Bedrock Structure Analysis Report, E.C. Electroplating, Garfield, New Jersey.* October, 2.Rutgers University. 2013. Monthly Precipitation in Northern New Jersey (Division 1) From 1895-2012, Available at: http://climate.rutgers.edu/stateclim_v1/data/north_njhistprecip.html. Accessed January 2013.

Sefres, M.E. 1994. *Natural Ground-water Quality in Bedrock of the Newark Basin, New Jersey. New Jersey Geological Survey*, Geological Survey report GSR 35.

Sovereign Consulting Inc. 2008. *Comprehensive Remedial Action Work Plan Addendum*. March 14

U.S. Census Bureau. 2000. American Fact Finder (2000 Census). DP-2 - Profile of Selected Social Characteristics: 2000. Available at: http://quickfacts.census.gov/qfd/states/34/3425770lk.html. Accessed January 2013.

U.S. Census Bureau. 2010. American Fact Finder (2010 Census). DP-1 - Profile of General Population and Housing Characteristics: 2010. Available at: http://quickfacts.census.gov/qfd/states/34/3425770lk.html. Accessed January, 2013.

U.S. Environmental Protection Agency (USEPA). 1988a. *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA.*

U.S. Environmental Protection Agency (USEPA). 1988b. *Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites*. December.

U.S. Environmental Protection Agency (USEPA). 1990. *National Oil and Hazardous Substances Contingency Plan*. Federal Register. Vol. 55, No. 46.

U.S. Environmental Protection Agency (USEPA). 1993. *Guidance for Evaluating the Technical Impracticability of Groundwater Restoration.* OSWER Directive 9234.2-25. September.

U.S. Environmental Protection Agency (USEPA). 1999. *Use of Monitored Natural Attenuation at Superfund, Resource Conservation and Recovery Act Corrective Action, and Underground Storage Tank Sites.* April 21.

U.S. Environmental Protection Agency (USEPA). 2000a. *In-situ Treatment of Soil and Groundwater Contaminated with Chromium: Technical Resource Guide*, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C. EPA/625/R-00/00. October.

U.S. Environmental Protection Agency (USEPA). 2000b. *Guide to Developing and Documenting Cost Estimates During the Feasibility Study.* EPA 54-R-00-002. OSWER 9355.0-75. July.

U.S. Environmental Protection Agency (USEPA). 2007. *Monitored Natural Attenuation of Inorganic Contaminants in Ground Water Volume 2: Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium*.

U.S. Environmental Protection Agency (USEPA). 2008. *Green Remediation: Incorporating Sustainable Environmental Practices into Remedial of Contaminated Sites.* EPA 542-R-08-002. Office of Solid Waste and Emergency Response. April.

U.S. Environmental Protection Agency (USEPA). 2010a. Memorandum regarding *E.C. Electroplating (Garfield Chromium Groundwater Contamination Site) – Determination of Significant Threat*. November

U.S. Environmental Protection Agency (USEPA). 2010b. EPA Region 2 Clean and Green Policy. http://www.epa.gov/region2/superfund/green_remediation/policy.html.

U.S. Environmental Protection Agency (USEPA). 2012a. *National Priorities Listing: Garfield Groundwater Contamination*. May 2.

U.S. Environmental Protection Agency (USEPA). 2012b. *Regional Screening Levels for Chemical Contaminants at Superfund Sites.*

U.S. Environmental Protection Agency (USEPA). 2014a. *EPA Removal Actions – Descriptions of Removal Activities at Residential and Commercial Properties Technical Memorandum.* City of Garfield, Bergen County, New Jersey.

U.S. Environmental Protection Agency (USEPA). 2014b. *Green Remediation Best Management Practices: Fact Sheets on Specific Remedies and Other Key Issues.* August 2014 Update.

U.S. Environmental Protection Agency (USEPA). 2015. Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites. August 2015.

University of Guelph, School of Engineering. 2013. Data Report on Rock Core Subsampling and Hexavalent Chromium Analysis at the Garfield Chromium Contamination Superfund Site, Garfield, NJ.

Walton, W. 1989. *Analytical Groundwater Modeling*, Lewis Publishers, Boca Raton, Florida.

Weston Solutions, Inc. (Weston). 2010. *HRS Summary Report, Garfield Ground Water Contamination, Garfield, Bergen County, New Jersey, CERCLIS ID No. NJN000206317*. August.

Weston Solutions, Inc. (Weston). 2013. *Removal Assessment Sampling Trip Report EC Electroplating, Garfield, Bergen County, New Jersey.* July 31.

Weston Solutions, Inc. (Weston). 2016. *Final Removal Action Report, Removal Action 2, EC Electroplating Site, 125 Clark Street.* Garfield, Bergen County, New Jersey. March.

Tables

TABLE 4-1
Applicable or Relevant and Appropriate Requirements
Garfield Groundwater Contamination Superfund Site
Feasibility Study

Act/Authority	Criteria/Issues	Citation	Brief Description	Applicability
Chemical-Specific				
Federal Safe Drinking Water Act	National Primary Drinking Water Standards - Maximum Contaminant Level Goals (MCLGs) and Maximum Contaminant Levels (MCLs)	40 CFR 141.62 and NJAC 7:10	Establishes health-based standards for public drinking water systems. Also establishes drinking water quality goals set at levels at which no adverse health effects are anticipated, with an adequate margin of safety. The NCP specifically states that MCLs will be used as ARARs for useable aquifers rather than the more stringent MCLGs.	Applicable to all alternatives, because all alternatives include remediation of the groundwater. New Jersey classifies all groundwater as Class IIA groundwater, considered suitable for drinking water, The MCLs were considered when selecting the Preliminary Remedial Goal (PRG) for Cr(VI). The Federal MCL for total chromium is 100 ppb. New Jersey sets the State MCL for total chromium at the federal MCL.
New Jersey Statutes and Rules	Groundwater Quality Standards	NJAC 7:9C	Defines groundwater classifications and establishes groundwater quality standards for various compounds. The site groundwater is classified as Class IIA suitable for drinking water.	The New Jersey Class IIA groundwater quality standards are applicable to all alternatives, as all alternatives include remediation of the groundwater. The PRG for Cr(VI) at the Garfield Superfund Site is set at the New Jersey Class IIA groundwater quality standard for total chromium of 70 µg/L.
NJDEP Chromium Workgroup	Chromium and No Further Action in Soils	Chromium Moratorium Memorandum from Commissioner Jackson (NJDEP 2007b).	Describes conditions under which no further action letters can be issued when 20 mg/kg of chromium can remain in unsaturated soils.	To be considered for evaluating RAOs 3 and 4.
Action-Specific				
Treatment and Discharge of Groundwater				
New Jersey Pollutant Discharge Elimination System (NJPDES) Discharges to Surface Water and POTWs	Surface Water and Groundwater Discharge Criteria	NJAC 7:14A-6.5, 12.11(d), 13	Establishes discharge standards for discharges to Publicly Owned Treatment Works (POTWs) and surface water. The nearest surface water body is the Passaic River, which is classified as an FW2-NT/SE2 water. Discharges to surface water from contaminated groundwater cleanup substantive requirements of the Category BGR- NJ0155438 would apply.	The discharge to surface water or discharge to POTW regulations may apply to all alternatives if these discharges are pursued. The alternative would need to comply with applicable standards for discharge limits and substantive requirements such as monitoring requirements. The BGR substantive requirements would also apply to treated construction dewatering, generally short term in nature (less than 6 months in duration), which may relate to the basement remediation portion of the alternatives.
New Jersey Pollutant Discharge Elimination System (NJPDES) Underground Injection	Class V Underground Injection	NJAC 7:14A-6.5, 7.5(b)3(vii), 7.8, 8.5, 8.5, 8.10(a), 8.12(a), 8.12(c) , 8.12(d), 8.16(b)1, 8.16(c)1 , 8.16(f)	Requirements for discharge to groundwater through underground injection wells.	The UIC regulations may apply to all alternatives because all alternatives currently anticipate reinjection of water. Because this is a CERCLA site with USEPA lead and NJDEP review, it is considered that the permit-by-rule applicability criteria in 7.5(b)3(vii) are met through NJDEP review of this FS and future Remedial Action Work Plan. Substantive permit-by-rule requirements such as monitoring would be adhered to, as proposed in an EPA-approved and NJDEP-reviewed work plan or remedial design.
New Jersey Pollutant Discharge Elimination System (NJPDES) Treatment Works Approval and Licensed Operator	Groundwater Treatment Ex Situ	NJAC 7:14-22.4(b)5 and NJAC 7:l0A-l.lO(c)1.	Treatment works approval and licensed operator are not required for discharges authorized under NJAC 7:14-7.5	May apply to all alternatives, as the discharge is assumed to meet the criteria for permit-by-rule, and all alternatives include aboveground treatment.
Water Supply Management Act and Implementing Rules	Extraction or Diversion of Groundwater or Surface Water Exceeding 70 gpm (100,000 gpd)	NJSA 58:1A-1 and NJAC 7:19	Rules governing the establishment of privileges to divert water, and the management of water quantity and quality. Includes schedule and reporting procedures.	NJSA 58:1-1A is applicable to alternatives that include extraction of groundwater exceeding a rate of 70 gpm. The rule (NJAC 7:19) is to be considered, as it applies administrative mechanisms through which objectives of the Water Supply Management Act can be achieved. Substantive requirements include conducting hydrogeologic testing, maintaining the passing flow at or above the 7-day, 10-year flow established by the United States Geologic Survey, mitigating adverse impacts on groundwater or surface water or there users, and use of a totalizer flowmeter. The NJDEP Bureau of Water Allocation (BWA) uses a CERCLA Permit-Equivalency application form for CERCLA site actions. Refer to Discharge to Surface Water and Discharge to Groundwater above for construction-related dewatering of less than 70 gpm.
Well Drillers and Pump Installers Act	Drilling Contractor Requirements	NJSA 58:4A-5 et seq. and NJAC 7:9D	Requirements for drilling and installing wells, licensing of well driller and pump installer, construction, and well casing specifications.	Applicable to all alternatives because they all include the installation of monitoring wells, extraction wells, or reinjection wells.
Preparation and Disposal of Waste				
New Jersey Solid and Hazardous Waste Regulations	Generation and Management of Solid and Hazardous Wastes	NJAC 7:26 Solid Waste and NJAC 7:26G Hazardous Waste	Establishes requirements for generators, transporters, and facilities that manage nonhazardous solid waste and hazardous waste	Applicable to solid and hazardous wastes generated during implementation of the remedial actions. Transportation and disposal occurs offsite; as such, those rules are not ARARs. Full administrative and substantive requirements must be followed offsite. Substantive requirements for hazardous waste generators may be relevant and appropriate to highly contaminated solid wastes. Water treatment systems that are operated under NJDPES are exempt from RCRA waste regulations.
Disposition of Material Generated During Site Investigations	Investigation-Derived Waste (IDW) Management	CERCLA and NJDEP Guidance Documents	Provides guidance on the disposition of IDW.	To be considered for all alternatives, for materials generated during well construction.
New Jersey Transportation Regulations (related to handling)	Onsite Preparation for Offsite Transportation	NJAC 16:49-2.1(a)1, 2, 3, 5,6	Rules for labeling of hazardous materials, packaging, and loading unloading.	Full compliance is required offsite. The waste preparation requirements are applicable to the onsite management of the waste in anticipation of shipping offsite.
Remedial Action - General				
Noise Control Act	Restrictions of Noise	NJSA 13:1G-1 et seq. and NJAC 7:29-1	Prohibits and restricts noise that unnecessarily degrades the quality of life. Sets maximum limits of sound from any industrial, commercial, public service or community service facility.	Relevant and appropriate to all alternatives. While the remedial action project does not fit the definition of the regulated activities, the regulation is relevant and appropriate. The final design will address compliance with this regulation to the extent practicable.
Soil Erosion and Sediment Control Act	Standards for Soil Erosion and Sediment Control	NJAC 2:90	The New Jersey Department of Agriculture, Bergen County Soil Conservation District governs all soil disturbances greater than 5,000 ft^2.	Applicable to alternatives that would disturb greater than 5,000 ft^2. The Bergen County Soil Conservation District follows the Seventh Edition, NJ Standards for Soil Erosion and Sediment Control, January 2014. Typical measures for shallow soil excavations include installation of silt fences, hay bales, and protection of storm drains. Implementation will comply with substantive requirements.
NJDEP Bureau of Non-Point Source Control	Stormwater Management	NJAC 7:8	Establishes requirements for best management practices and stormwater protection. The general permit for construction (5G3) substantive requirements would likely apply.	Applicable to all alternatives that include clearing, grading, and excavation (generally, construction activities) that disturb 1 acre or more of land.
Location-Specific				
National Historic Preservation Act	Protects historic places	16 USC 470 Section 106 et. seq.	Requires federal agencies to take into account the effect of any federally-assisted undertaking or licensing on any district, site, building, structure, or object that is included in or is eligible for inclusion in the National Register of Historic Places.	Applicable if the portions of the site to be disturbed by remediation include historic or cultural resources. Further evaluation is needed.
New Jersey Register of Historic Places Act	Protects historic places	NJSA 12:1B-15.128 et seq.	Official list of New Jersey's historic resources of local, state, and national interest. Closely modeled after the National Register program. Both Registers have the same criteria for eligibility, nomination forms, and review process. Intended to protect properties significant in architecture, history, archaeology, engineering and/or culture.	Applicable if the portions of the site to be disturbed by remediation include historic or cultural resources. A preliminary search indicates that the properties listed below are in Bergen County: Erie Railroad Right-of-Way westward from Hudson, Jersey City at Coles; Erie Railroad Main Line Historic District (ID#218); Remains of Zabriskie's dock (ID#513). Further evaluation is needed to determine if they are within the site boundaries.

Notes:

µg/L - microgram per liter
ARARs - applicable or relevant and appropriate requirements
BWA - Bureau of Water Allocation
CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act of 1980
Cr(VI) - hexavalent chromium
EPA - US Environmental Protection Agency
ft^2 - square foot
FS - feasibility study
gpd - gallons per day
gpm - gallons per minute
MCLGs - maximum contaminant level goals

MCL - maximum contaminant level
mg/kg - milligram per kilogram
NCP - National Oil and Hazardous Substance Pollution Contingency Plan
NJDEP - New Jersey Department of Environmental Protection
NJPDES - New Jersey Pollutant Discharge Elimination System
POTW - Publicly Owned Treatment Works
ppb - parts per billion
PRG - preliminary remediation goal
RAO - remedial action objective
UIC - underground injection control

TABLE 4-2

Comparison of Site Groundwater Concentrations to NJAC 7:14A-12 Appendix B Limits

Garfield Groundwater Contamination Superfund Site

Feasibility Study

Chemical	Minimum Detected Concentration		Maximum Detected Concentration		Units	FOD	Range of MDL	Average Concentration[a]	NJAC 7:14A-12 Effluent Standards[b]	PVSC Limits
1,1,1-Trichloroethane	0.1	J	1.7		µg/L	9 / 71	0.062 - 0.1	0.15	21	
1,1,2-Trichloro-1,2,2-trifluoroethane	0.28	J	0.83		µg/L	5 / 71	0.08 - 0.1	0.12		
1,1-Dichloroethane	0.11	J	7.3		µg/L	4 / 71	0.079 - 0.1	0.30	22	
1,1-Dichloroethene	0.34	J	2		µg/L	7 / 71	0.075 - 0.1	0.20	6	
1,2,3-Trichlorobenzene	1.7		1.7		µg/L	1 / 71	0.1 - 0.3	0.22		
1,2,4-Trichlorobenzene	4.2		4.2		µg/L	1 / 71	0.1 - 0.12	0.17	68	
2-Butanone	1.9	J	6.8		µg/L	4 / 71	1.6 - 1.9	1.86		
2-Methylnaphthalene	0.6	J	0.6	J	µg/L	1 / 71	0.41 - 2.4	1.21		
2-Methylphenol	0.18	J	2.9	J	µg/L	5 / 71	0.6 - 2.2	1.24		
4,4'-DDD	0.0055	J	0.0055	J	µg/L	1 / 71	.0092 - 0.009	0.06	0.04	
4,4'-DDT	0.0086	J	0.0086	J	µg/L	1 / 71	0.009 - 0.009	0.06	0.06	
4-Methylphenol	0.19	J	0.27	J	µg/L	2 / 71	0.56 - 2.4	1.25		
Acetone	18		1000		µg/L	15 / 71	2.2 - 3.1	36.82		
Acetophenone	1.5	J	33		µg/L	18 / 71	0.28 - 2.5	2.86		
alpha-BHC	0.0035	J	0.0035	J	µg/L	1 / 71	.0049 - 0.004	0.03	0.02	
alpha-Chlordane	0.0025	J	0.01	J	µg/L	2 / 67	.0048 - 0.004	0.03		
Aluminum, dissolved	7.6	J	1400		µg/L	45 / 128	2.4 - 28	58.23		
Aluminum, total	10.5	J	1870		µg/L	48 / 116	2.4 - 28	140.16		
Antimony, dissolved	2.1	J	390		µg/L	14 / 142	0.089 - 11	12.95		
Antimony, total	2.4		420		µg/L	16 / 142	0.089 - 11	13.95	140	
Aroclor-1260	0.29	J	0.65	J	µg/L	3 / 71	0.04 - 0.4	0.23		
Arsenic, dissolved	1.6		120		µg/L	70 / 142	0.04 - 4.8	7.54		
Arsenic, total	1.1		110		µg/L	74 / 142	0.04 - 4.8	7.68	50	
Barium, dissolved	11.4	J	588		µg/L	109 / 142	0.05 - 28	134.36		
Barium, total	17.1	J	2060		µg/L	106 / 142	0.05 - 28	148.31		
Benzene	0.24	J	0.58		µg/L	9 / 71	0.076 - 0.1	0.12	7	
Benzo(a)anthracene	0.24	J	0.24	J	µg/L	1 / 71	0.9 - 2.6	1.55	10	
Benzo(a)pyrene	0.23	J	0.23	J	µg/L	1 / 71	2.3 - 2.7	2.40	20	
Benzo(b)fluoranthene	0.23	J	0.23	J	µg/L	1 / 71	0.75 - 2.1	1.24	10	
Benzo(g,h,i)perylene	0.29	J	0.29	J	µg/L	1 / 71	1.7 - 3.5	2.30		
Benzo(k)fluoranthene	0.27	J	0.27	J	µg/L	1 / 71	1.7 - 3.1	2.17	20	
Beryllium, total	48.8		48.8		µg/L	1 / 142	0.024 - 1.4	1.16		
Bromodichloromethane	0.21	J	1.8		µg/L	21 / 71	0.1 - 0.25	0.30		
Bromoform	0.13	J	0.2	J	µg/L	2 / 71	0.1 - 0.11	0.11	8.6	
Bromomethane	0.21	J	0.21	J	µg/L	1 / 71	0.072 - 0.1	0.09		
Cadmium, total	46.4		46.4		µg/L	1 / 142	0.018 - 1.5	1.11	50	
Calcium, dissolved	9900		156000		µg/L	142 / 142	17.8 - 130	58,391.55		
Calcium, total	9500		158000		µg/L	142 / 142	17.8 - 130	58,831.69		
Caprolactam	1.1	J	39		µg/L	4 / 71	1.1 - 2.9	2.42		
Carbon Tetrachloride	0.12	J	1		µg/L	11 / 71	0.061 - 0.2	0.16	6	
Chloroethane	0.33	J	0.33	J	µg/L	1 / 71	0.076 - 0.2	0.14	104	
Chloroform	0.44	J	4.9		µg/L	44 / 71	0.082 - 0.1	1.09	11.4	
Chloromethane	0.21	J	1.2		µg/L	20 / 71	0.058 - 0.2	0.22		
Chromium (hexavalent), dissolved	0.015		86500		µg/L	146 / 159	0.01 - 300	3,704.47	50	
Chromium, dissolved	2.2		82000		µg/L	118 / 158	0.044 - 3.3	3,747.25		
Chromium, total	2.3		89800		µg/L	131 / 158	0.044 - 3.3	3,952.58	50	
Chrysene	0.21	J	0.21	J	µg/L	1 / 71	1.1 - 3.1	1.87	20	
cis-1,2-Dichloroethene	0.13	J	6.8		µg/L	14 / 71	0.1 - 0.1	0.30		
Cobalt, dissolved	1.3	J	1.7	J	µg/L	3 / 142	0.014 - 5.4	2.79		
Cobalt, total	1.5	J	458		µg/L	4 / 142	0.014 - 5.4	6.02		
Copper, dissolved	0.5	J	8.2		µg/L	33 / 142	0.43 - 5	3.72		
Copper, total	0.47	J	250		µg/L	41 / 142	0.43 - 2.5	5.88	50	3600
Cyanide	3.2	J	21.9		µg/L	15 / 142	0.43 - 1.9	2.76	100	
Cyclohexane	0.25	J	0.25	J	µg/L	1 / 71	0.058 - 0.2	0.13		
Dibenzo(a,h)anthracene	0.25	J	0.25	J	µg/L	1 / 71	0.52 - 3.5	1.68	20	
Dibromochloromethane	0.18	J	0.89		µg/L	16 / 71	0.1 - 0.14	0.19		
Dieldrin	0.0018	J	0.22		µg/L	17 / 71	.0094 - 0.009	0.07	0.03	
Diethylphthalate	3.4	J	3.4	J	µg/L	1 / 71	0.92 - 2.6	1.63	81	
Dimethylphthalate	1.2	J	5.6		µg/L	4 / 71	0.57 - 2.1	1.32	19	
Di-n-octylphthalate	0.38	J	0.38	J	µg/L	1 / 71	1.8 - 3.2	2.25		
Fluoranthene	0.15	J	0.2	J	µg/L	2 / 71	0.66 - 2.4	1.30	25	
gamma-Chlordane	0.0014	J	0.034	J	µg/L	12 / 71	.0073 - 0.007	0.03		
Heptachlor	0.0024	J	0.0024	J	µg/L	1 / 71	.0063 - 0.006	0.03	0.02	
Indeno(1,2,3-cd)pyrene	0.25	J	0.25	J	µg/L	1 / 71	1.7 - 3.1	2.15	20	
Iron, dissolved	12.6	J	1900		µg/L	11 / 142	9.3 - 14	29.56		
Iron, total	22.4	J	1200		µg/L	40 / 142	9.3 - 14	96.10	1000	
Isophorone	0.34	J	3	J	µg/L	5 / 71	0.44 - 2.5	1.26	20	
Lead, total	1.2		40.6		µg/L	8 / 142	0.074 - 2.4	2.38	50	1000
Magnesium, dissolved	123	J	50000		µg/L	138 / 142	2.7 - 140	20,356.64		
Magnesium, total	519	J	44000		µg/L	141 / 142	2.7 - 140	19,758.73		
Manganese, dissolved	1.2		650		µg/L	64 / 142	0.063 - 3	37.02		
Manganese, total	1.1		1900		µg/L	82 / 135	0.063 - 3	62.23		
Mercury, dissolved	0.011	J	0.086	J	µg/L	20 / 142	0.0054 - 0.04	0.03		
Mercury, total	0.027	J	0.31	J	µg/L	14 / 142	0.0054 - 0.04	0.03	1	80
Methyl tert-Butyl Ether	0.22	J	1.5		µg/L	3 / 71	0.1 - 0.11	0.13		
Methylene Chloride	0.24	J	0.24	J	µg/L	1 / 71	0.025 - 0.5	0.28	9.4	
Nickel, dissolved	0.53	J	74		µg/L	36 / 142	0.037 - 5.4	4.34		
Nickel, total	0.053	J	463		µg/L	39 / 142	0.037 - 5.4	8.18	72	3900
Perfluorobutane Sulfonate	2.6		14		µg/L	7 / 7	0.1 - 0.1	8.29		
Perfluorodecanoic Acid	0.25	J	0.85		µg/L	4 / 7	0.1 - 0.1	0.31		
Perfluoroheptanoic Acid	6.8		10		µg/L	7 / 7	0.2 - 0.2	8.60		
Perfluorohexane Sulfonate	4.8		10		µg/L	7 / 7	0.2 - 0.2	8.07		
Perfluorohexanoic Acid	7.5		12		µg/L	7 / 7	0.7 - 0.7	10.17		
Perfluorononanoic Acid	1.1		4.4		µg/L	6 / 7	0.05 - 0.05	2.11		
Perfluorooctane Sulfonate	10		490		µg/L	7 / 7	0.1 - 1	144.43		
Perfluorooctanoic Acid	35		56		µg/L	7 / 7	0.2 - 0.2	47.29		
Perfluoropentanoic Acid	7.1		11		µg/L	7 / 7	0.4 - 0.4	8.64		
Perfluoroundecanoic Acid	0.26	J	0.26	J	µg/L	1 / 7	0.2 - 0.2	0.21		
Phenol	1.2	J	6.2		µg/L	4 / 71	0.71 - 2.2	1.43	15	
Potassium, dissolved	173	J	120000		µg/L	125 / 142	3.7 - 150	5,581.67		
Potassium, total	172	J	180000		µg/L	125 / 142	3.7 - 150	7,724.56		
Selenium, dissolved	3	J	61		µg/L	7 / 142	0.24 - 11	6.90		
Selenium, total	0.35	J	48		µg/L	19 / 142	0.24 - 11	7.16	50	
Silver, total	2.3		46.7		µg/L	3 / 142	0.022 - 1.3	1.23	25	
Sodium, dissolved	11600		217000		µg/L	142 / 142	7 - 462	45,976.06		
Sodium, total	10800		224000		µg/L	142 / 142	7 - 462	47,478.17		
Tetrachloroethene	0.11	J	53		µg/L	48 / 71	0.076 - 0.2	1.89	16	
Thallium, total	30.6	J	30.6	J	µg/L	1 / 142	0.035 - 7.6	4.78	17	
Toluene	0.23	J	220		µg/L	34 / 71	0.075 - 0.1	8.68	26	
trans-1,2-Dichloroethene	0.24	J	0.24	J	µg/L	1 / 71	0.058 - 0.1	0.08	21	
Trichloroethene	0.13	J	290		µg/L	37 / 71	0.067 - 0.1	12.05	5.4	
Vanadium, dissolved	2.4	J	440		µg/L	31 / 129	0.094 - 5.6	12.63		
Vanadium, total	3	J	576		µg/L	27 / 142	0.094 - 5.6	15.11		
Zinc, dissolved	0.61	J	21.7		µg/L	43 / 142	0.5 - 5.7	5.82		
Zinc, total	0.82	J	443		µg/L	59 / 142	0.5 - 5.7	12.44	100	4200
pH	5.01		13.3			290 / 290	-	7.84	6 to 9	
TOC (assumes 1:1 correlation with BOD_5)	1		250		mg/L	83 / 139	0.2 - 2.0	8.54	30 (monthly average) 45 (weekly average)	

Notes:

Grey cells indicate exceedance of the NJAC 7:14A-12 Effluent Standards (Appendix B) limit. No exceedances are noted under the PVSC limits.

BOD_5 - biological oxygen demand (5-day)

FOD - frequency of detection

J - Analyte detected at an estimated concentration

MDL - method detection limit

µg/L - micrograms per liter

mg/L - milligrams per liter

PVSC - Passaic Valley Sewerage Commission

TOC - total organic carbon

[a]Average concentrations were calculated using the detection level for nondetect results. This results in a conservative estimate of the average concentrations in cases higher than the maximum detected concentration.

[b]The limits are for FW-2 waters and represent the monthly average limit. For compounds with no monthly average limit, it represents the daily maximum limit.

TABLE 5-1
Preliminary Technology Screening for Hexavalent Chromium
Garfield Groundwater Contamination Superfund Site
Feasibility Study

General Response Actions	Remedial Technology	Process Option	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative Operations & Maintenance Cost	Retained/ Not Retained	Screening Comment
No Action	No Action	No Action	No remedial actions taken.	Low No remedial actions are taken. Does not address exposure to Cr(VI) in basements.	High	Low	Low	Retained	Retained in accordance with the NCP (40 CFR 300).
ICs	ICs	Access and land use restrictions	Non-engineered instruments (e.g., administrative/legal) that help minimize the potential for human exposure to contaminated groundwater and/or protect the integrity of the remedy.	High ICs would prevent the use of groundwater from the aquifers.	High	Low	Low	Retained	Although ICs do not address mass reduction, hot spot treatment or plume cutoff, they may be adequate to limit exposure to contaminated groundwater when implemented as a component of an alternative in conjunction with other remedial actions.
Monitoring	Monitoring	Monitoring	Monitoring of groundwater plume to track plume growth and evaluate performance of other remedial actions. Typically combined with other actions that manage the source areas and mitigate exposure.	Moderate/High Monitoring is effective when used in conjunction with institutional controls or engineered passive or active remediation measures.	High	Low	Low/Moderate	Retained	Retained as a component of a remedial alternative.
	MNA	MNA	Relies on natural attenuation processes such as biological and chemical reduction, adsorption, dilution, and dispersion to manage Cr(VI) plumes. Monitors groundwater plumes to track natural attenuation processes until RAOs are achieved. Typically combined with other actions that manage the source areas and mitigate exposure. Contingent actions are identified in the event plume migration or risks exceed levels appropriate for MNA.	Low/Moderate There is significant uncertainty on the potential for MNA to be effective. Long-term Cr(VI) concentration trend data is not available to define if the plume is static or shrinking. In addition, the groundwater geochemistry is generally oxidizing and has relatively high pH, which limits abiotic reduction, microbial reduction, or sorption of the Cr(VI).	High	Low	Low/Moderate	Not Retained	Insufficient information to verify that MNA can be effective. Further monitoring and modeling at the site may demonstrate that natural attenuation processes are occurring so that it could be incorporated at a later date.
Pump and Treat Collection	Extraction	Groundwater Extraction System	Operation of groundwater extraction wells to remove Cr(VI) from aquifers. Groundwater is treated ex situ and discharged.	Moderate Groundwater extraction is a proven technology for the collection of contaminated groundwater from highly to moderately permeable aquifers. However, it would be only moderately effective for mass removal in dual porosity and complex fracture flow aquifers. Although groundwater in secondary pore spaces and mobile fractures would be extracted, Cr(VI) in immobile groundwater would not be extracted.	Low/Moderate Could be implemented using vertical or horizontal wells. However, installation of extraction wells and piping network would be limited by access restrictions and by high density of residential and commercial buildings. These access restrictions limit where groundwater can be extracted and increases likelihood that immobile groundwater will not be extracted.	Moderate	Moderate/High	Retained	Retained to collect contaminated groundwater for plume-wide or more targeted remedial actions.
Ex Situ Treatment	Chemical	Ion Exchange	Ions from the aqueous phase are removed by exchange with innocuous ions on the exchange medium.	Moderate/High Effective for Cr(VI) treatment.	High Vendors and equipment readily available. Will require construction of a central treatment facility.	Moderate	Moderate/High	Retained	Proven technology to remove Cr(VI) from extracted groundwater. High pH groundwater may require pre-treatment to reduce pH.
		Chemical Reduction and Precipitation	Dissolved contaminants are transformed into an insoluble solid/sludge, which is removed by flocculation, sedimentation, and filtration. Contaminants are removed with the sludge. Chemicals used in process represent potential handling risk. Treatment waste sludge would require stabilization and landfill disposal.	Low/Moderate Effective for Cr(VI) treatment.	Moderate/High Vendors and equipment readily available.	Moderate/High	Moderate/High	Retained	Proven technology for Cr(VI) remediation.
		Electrocoagulation	Relies on electrochemical generation of ferrous iron. The ferrous iron reduces metals that are susceptible to reduction and converts them to insoluble solids, which are removed by sedimentation and filtration.	Low/Moderate Not widely used for Cr(VI) removal.	Low/Moderate Additional development and testing would be required.	Moderate/High	Moderate	Not Retained	Not a proven technology for full-scale applications. High maintenance demands.
		Wetlands	Extracted groundwater is pumped to a constructed wetland where contaminants are biologically reduced, or taken up by plants and algae.	Moderate Cr(VI) can be removed in wetlands primarily by microbiological and chemical reduction. Some Cr(VI) uptake by wetland plants may also occur.	Low/Moderate May require large surface area for extended period of time.	Low Depends on land requirements.	Low	Not Retained	Not retained due to limited land availability. Depending on contaminant levels and potential co-contaminants, treatment wetlands may become a draw and an ecological risk for wildlife.
		Subgrade Bioreactors	Extracted groundwater is pumped into a lined excavated area that has been backfilled with organic media (for example, wood mulch with ZVI). Cr(VI) is biologically reduced as it passes through the media. A second aeration/filtration stage could be provided to remove any biological byproducts (for example, iron) and solids prior to infiltrating or injecting back to groundwater.	Moderate Has not been demonstrated at full scale for Cr(VI) remediation. Pilot-scale treatability testing required. Probable loss of treatment effectiveness and freezing issues in winter.	Moderate/High Excavation and backfilling is easy to implement. Piping can be incorporated into the design to facilitate future delivery of liquid carbon sources (for example, vegetable oil). Treatability testing required to verify implementability.	Low/Moderate Depends on land requirements.	Low	Not Retained	Not retained due to limited land availability and possible odor issues in high-density residential or commercial areas.

TABLE 5-1

Preliminary Technology Screening for Hexavalent Chromium

Garfield Groundwater Contamination Superfund Site

Feasibility Study

General Response Actions	Remedial Technology	Process Option	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative Operations & Maintenance Cost	Retained/ Not Retained	Screening Comment
	Biological	Bioreactors	Groundwater is amended with electron donor (carbon source) and passes through a matrix (fixed bed, fluidized bed, or membranes) with microbial films, where contaminants are biologically reduced. Effluent is oxygenated, filtered, and amended before recharge back into the ground. Similar system recently implemented for denitrification and Cr(VI) at the 200 East Area of the Hanford Reservation, Washington State.	Low/Moderate Bioreactors are effective but less commonly used for Cr(VI) reduction.	Moderate Vendors and equipment readily available. Implementation of a central biological treatment plant may be limited by land availability and access restrictions.	High	Moderate	Retained	Best applied for treatment of localized highly contaminated source area groundwater. Treatment plant size considerations and available land will need to be evaluated.
		Phytoremediation	Use of plants and their associated rhizospheric microorganisms to remove, reduce/degrade, or contain chemical contaminants in soil or groundwater. Contaminants in groundwater can also be removed by applying it as irrigating water for plants.	Low/Moderate Could be used as a barrier approach, but there would be challenges with the depth to the water table even close to the river.	Low/Moderate Requires large surface area for plants. Potential challenges with implementation near river.	Low	Low	Not Retained	Would only be effective for low concentrations of contaminants where groundwater is shallow over long time frames, or when applied as irrigation water. Bioaccumulation in plants may pose risk to ecological receptors.
Discharge	Physical	Membrane Separation (for example, Reverse Osmosis)	Water pressure is used to force water molecules through a very fine membrane, leaving the contaminants behind. Purified water is collected from the "clean" or "permeate" side of the membrane, and water containing the concentrated contaminants is disposed of.	High With the appropriate design, reverse osmosis can be effective for almost any compound.	Low/Moderate Vendors and equipment readily available, although additional site-specific testing would be required. Pretreatment likely necessary, and a large volume of brine would be produced that would need to be treated and disposed.	High	High	Not Retained	Large volumes of brine produced would require further treatment and disposal.
	Discharge	Groundwater Injection Wells	Treated groundwater is injected into onsite wells.	High Very effective method for disposing of treated water. Disposal enhances hydraulic control and capture of plume.	Low/Moderate The wells may be subject to clogging due to the buildup of chemical precipitates or microbial biofouling. Installation of injection wells and piping network would be limited by access restrictions and by high density of residential and commercial buildings.	Low	Low/Moderate	Retained	Injection of treated water can be effective for hydraulic control. Can be used to enhance plume containment and mass reduction by manipulating capture zones.
		Surface Infiltration	Treated groundwater is infiltrated into onsite trenches, located outside of zones of known source areas.	High Effective means of disposal and may enhance contaminant flushing, hydraulic control and capture of plume if they can be located appropriately.	Low/Moderate Although infiltration is easy to engineer, full-scale surface infiltration trenches would be difficult to implement in high-density areas.	Low Trenches are lower cost than wells.	Low/Moderate	Not Retained	Not retained due to limited land availability for successful implementation. Raising shallow water table may result in water infiltrating into basements.
		Beneficial Reuse of Treated Water	Use of treated water for a beneficial use such as irrigation or dust control.	High Effective means of treated water disposal.	Moderate/Low No known facility in area that could use large quantities of water. Potential short-term or intermittent use for dust control for nearby earthwork possible after treatment.	High	Low	Not Retained	Not retained because a beneficial use has not yet been identified. The City of Garfield will be consulted with regarding beneficial reuse in the future.
		POTW	Discharge to the local POTW.	High Effective means of treated water disposal.	High Need to evaluate discharge limits and pre-treatment requirements.	Moderate	Moderate	Retained	Retained as a possible component of a pump-and-treat alternative.
		Surface Water Discharge (NPDES)	Discharge of treated groundwater directly to the river at a permitted outfall.	High Effective means of treated water disposal.	High Commonly practiced for treated wastewater.	Low	Low	Retained	Retained as a possible component of a pump-and-treat alternative.
In Situ Treatment	Chemical	In Situ Chemical Reduction	Subsurface delivery of chemical reductants (such as calcium polysulfide) within plume to stimulate reduction of contaminant.	Moderate Effective in reducing Cr(VI) to insoluble Cr (III) where reagent contact with contaminants are achieved. Tight injection well spacing may be required due to fast kinetics of chemical reductants. Plume treatment would be limited due to inaccessibility to low permeability zones and immobile groundwater residing in disconnected fracture networks. Size, longevity, and intensity of in situ treatment zone can be adjusted by use of different chemicals, dosage, and frequency of injections.	Moderate Would require a large number of injection wells. Does not require extensive piping system. Chemicals used for in situ reduction likely represent a handling and transport risk in high population density areas. Requires a large volume of water for injection.	Moderate/High Likely higher capital cost compared to In situ biological due to chemical costs and higher injection frequency.	Moderate/High	Retained	Retained as a possible component of a source area treatment alternative, targeting contamination within the overburden of the ECE property.
	Biological	In Situ Biological Treatment (Anaerobic)	Subsurface delivery of various organic substrates (liquid or gaseous) in a regular pattern of wells in the aquifer to stimulate anaerobic bioreduction of Cr(VI).	Moderate Relatively flexible and effective process option when used at appropriate sites. Plume treatment would be limited due to inaccessibility to low permeability zones and immobile groundwater residing in disconnected fracture networks. Size, longevity, and intensity of in situ treatment zone can be adjusted by use of different organic substrates, dosage, and frequency of injections.	Moderate/High Would require a large number of injection wells. Does not require extensive piping system. Requires a large volume of water for injection.	Moderate/High Dependent on number and type of wells.	Moderate/High	Retained	Can be used for plume-wide, source area, or targeted hot spot remediation.

TABLE 5-1
Preliminary Technology Screening for Hexavalent Chromium
Garfield Groundwater Contamination Superfund Site
Feasibility Study

General Response Actions	Remedial Technology	Process Option	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative Operations & Maintenance Cost	Retained/ Not Retained	Screening Comment
	Physical	Flushing	Clean/treated water is injected to flush out contaminated groundwater to expedite remediation of plumes. Would be a component of a pump-and-treat system.	Moderate Flushing can be used to increase effectiveness of pump and treat systems by mobilizing residual contamination in lower permeability layers. Not effective in flushing Cr(VI) in immobile groundwater residing in disconnected fracture networks. Increases likelihood of mounding in overburden and exacerbating basement infiltration.	Low/Moderate Installation of injection wells and piping network would be limited by access restrictions and by high density of residential and commercial buildings. These access restrictions limit where the plume can be flushed and increases likelihood that immobile groundwater will not be flushed.	Moderate Costs for wells and piping.	Moderate/High	Retained	The associated pump and treat systems should be designed to minimize potential for mounding in overburden, or simply diluting or spreading contamination.
Containment	Soil Mixing	Soil Mixing	Subsurface mixing of saturated soils with an amendment, such as bentonite grout or chemical reducing agent, to reduce migration of contamination from the source area to the downgradient groundwater plume. Would require disturbance of previously excavated area within the ECE Property.	Moderate Effective if mixing zone conditions are maintained. Would not be effective in treating the bulk of the groundwater plume. Is only effective in areas where groundwater contacts mixed soil (i.e. the saturated zone).	Low Installation to substantial depths is very difficult, is only possible for the overburden saturated zone and the weathered bedrock. May be limited to access restrictions within the ECE property. Would require disturbance of previously excavated area within the ECE Property.	High	Low	Retained	Retained as a possible component of a source area treatment alternative, targeting contamination within the overburden of the ECE property.
	Physical	Containment Wall (e.g. slurry wall or sheet pile wall)	Slurry wall barriers consist of a vertical barrier perpendicular to the groundwater flow direction, partially filled with bentonite slurry, grout, or other low- permeability material. A sheet pile barrier could also be used. The barrier is typically keyed into a lower-permeability zone.	Low Effectiveness depends on the continuity of the wall and the ability to key into a confining unit, which will be difficult to achieve because of depth. Does not reduce toxicity or volume of contaminants by itself. This technology requires groundwater extraction to control groundwater pressures from building up behind the barrier and potentially damaging the barrier or causing groundwater to flow under, over, or around the barrier. Not effective in treating the bulk of the plumes. Not effective for overburden plume due to existing exposure risk in basements.	Low Installation to substantial depths is very difficult, but possible for shallow depths.	High	Low Moderate	Not Retained	Limited applicability for the overburden since exposure risk in basements already exists, and plume is already intercepted by the Passaic River. Step 3 BERA indicated that there is no ecological risk in the Passaic River due to Cr(VI). Installation in bedrock is not feasible due to depth.
	Chemical	Chemical PRB using soluble chemicals	Subsurface injection or infiltration of soluble reducing chemicals (such as calcium polysulfide or sodium dithionite) along cross-gradient rows transecting plume. Chemicals are retained in the aquifer matrix so that contaminants are passively removed as groundwater moves through the treatment zone barriers.	Low Effective if barrier treatment zone conditions are maintained. High flows of highly aerobic groundwater and changing water levels are likely to necessitate more frequent amendments. Creating continuous barrier via injection would be difficult due to inaccessibility to low permeability zones and disconnected fracture networks. Not effective in treating the bulk of the plumes. Not effective for overburden plume due to existing exposure risk in basements.	Moderate Implementation of a barrier through injection wells may be limited by access restrictions, but could potentially be achieved along the City right-of way. Chemicals used for in situ reduction likely represent a handling and transport risk in high population density areas.	Moderate/High Dependent on number and type of wells.	Moderate/High	Not Retained	Limited applicability for the overburden since exposure risk in basements already exists, and plume is already intercepted by the Passaic River. Step 3 BERA indicated that there is no ecological risk in the Passaic River due to Cr(VI). Less treatment flexibility than with in situ biological barriers. Trenching application would not be feasible due to depth.
		Chemical PRB using ZVI	Subsurface installation of ZVI or ferrous sulfide PRB through injection or trenching along cross-gradient rows transecting plume. ZVI retained in the aquifer matrix so that contaminants are passively removed as groundwater moves through the treatment zone barriers.	Low Effective if barrier treatment zone conditions are maintained. High flows of highly aerobic groundwater and changing water levels are likely to necessitate more frequent amendments. Iron delivered may cause well clogging/fouling (potential higher than with biological amendments). Not effective in treating the bulk of the plume. Not effective for overburden plume due to existing exposure risk in basements.	Moderate Can be implemented with injection wells or trenching. Trenching would be difficult to implement for bedrock due to depth of contamination. Possibly effective for overburden aquifer, Implementation of a barrier may be limited by access restrictions, but could potentially be achieved along the City right-of way.	Moderate/High Dependent on number and type of wells. ZVI generally more expensive as compared to biological substrates.	Moderate	Not Retained	Limited applicability for the overburden since exposure risk in basements already exists, and plume is already intercepted by the Passaic River. Step 3 BERA indicated that there is no ecological risk in the Passaic River due to Cr(VI). Trenching application would not be feasible due to depth.
	Biological	Biological PRB	Subsurface delivery of electron donors along cross-gradient rows transecting plume. Residual reducing byproducts and biomass are retained in the aquifer matrix so that contaminants are passively removed as groundwater moves through the treatment zone barriers.	Low Effective if barrier treatment zone conditions are maintained. Periodic amendment may be required to maintain reducing conditions. Creating continuous barrier via injection would be difficult due to inaccessibility to low permeability zones and disconnected fracture networks. Not effective in treating the bulk of the plume. Not effective for overburden plume due to existing exposure risk in basements.	Moderate/High Can be implemented with injection wells or trenching. Trenching would be difficult to implement for bedrock due to depth of contamination. Possibly effective for overburden aquifer. Implementation of a barrier may be limited by access restrictions, but could potentially be achieved along the City right-of way.	Moderate Dependent on number and type of wells.	Moderate	Not Retained	Limited applicability for the overburden since exposure risk in basements already exists, and plume is already intercepted by the Passaic River. Step 3 BERA indicated that there is no ecological risk in the Passaic River due to Cr(VI). Trenching application would not be feasible due to depth.

TABLE 5-1
Preliminary Technology Screening for Hexavalent Chromium
Garfield Groundwater Contamination Superfund Site
Feasibility Study

General Response Actions	Remedial Technology	Process Option	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative Operations & Maintenance Cost	Retained/ Not Retained	Screening Comment
				Low	Low/Moderate	Moderate	Moderate		
	Hydraulic Control	Hydraulic Containment via Extraction	Install extraction wells perpendicular to the long axis of the plume to cut off the plume at the most downgradient location that is practicable (for example, well installed upgradient of, and parallel to, the river). Extracted water would require treatment or could be amended with organic substrate and re-injected upgradient.	Generally effective method to contain and cutoff plumes, and provides some mass removal to accelerate plume cleanup. However, it may be only moderately effective for complete capture in dual porosity and complex fracture flow aquifers. Not effective in treating the bulk of the plume. Not effective for overburden plume due to existing exposure risk in basements.	Implementation may be limited by access restrictions. Would likely require construction of an extensive piping network in an area with a high population density.			Non Retained	Limited applicability for the overburden since exposure risk in basements already exists, and plume is already intercepted by the Passaic River. Step 3 BERA indicated that there is no ecological risk in the Passaic River due to Cr(VI).
				High	Moderate	Moderate/High	Low		
Removal	Excavation	Excavation	Removal of materials from the water table to contact with competent bedrock. Excavated soil is segregated to determine disposal or treatment requirements, and all material above the applicable standards would be removed. Treatment of impacted material may be needed prior to disposal at an appropriate facility. Technologies to implement excavation vary based on depth and complexity. Deeper excavation would require implementation of more-complex technologies, such as using soldier piles.	Removes impacted material	Excavation beyond the water table requires implementation of more complex technologies than standard excavation (ground surface to water table). Excavation at the ECE property could potentially affect adjacent structures.	Moderate to high cost as a result of implementation of complex technologies	No associated O&M cost because impacted material is removed	Retained	Retained for removal of contaminated source area material from the water table to contact with competent bedrock. Not retained for the overburden or bedrock plumes.
				High	Moderate	Low	Low		
Minimize Infiltration	Dewatering	French Drain	Dewatering can be completed by installing French drains, which are trenches covered with gravel or rock or containing a perforated pipe to redirect groundwater away from the basement. Once the groundwater is captured by the French drain, it would need to be routed for discharge at an appropriate location, similar to a pump-and-treat technology	Proven technology to prevent groundwater from infiltrating into basements.	Moderate	Costs for constructing a French drain are low. Capital costs driven by groundwater discharge.	O&M costs for a French drain are low. O&M costs driven by groundwater discharge.	Retained	Currently used by the USEPA to address infiltration of Cr(VI)-contaminated groundwater into basements at the Site. Captured groundwater has been re-routed and discharged to the sanitary sewer.
				High	High	Low	Low		
	Basement cleaning and waterproofing	Basement cleaning and waterproofing	Involves inspecting basements and applying sealant to basement floors and walls to prevent future infiltration of groundwater containing Cr(VI)	Proven technology to prevent groundwater from infiltrating into basements.	Simple technology to implement. Currently used by the USEPA to address infiltration of Cr(VI) into basements at the Site.			Retained	Currently used by the USEPA to address infiltration of Cr(VI) into basements at the Site.

Notes:
Cr(VI) - hexavalent chromium
Cr(III) - trivalent chromium
ECE - E.C. Electroplating, Inc.
ICs - institutional controls
MNA - monitored natural attenuation
POTW - Publically Owned Treatment Works
PRB - permeable reactive barrier
ZVI - zero valent iron

TABLE 6-1
Focused Technology Screening for Hexavalent Chromium Treatment in Bedrock
Garfield Groundwater Contamination Superfund Site
Feasibility Study

General Response Actions	Remedial Technology	Process Option	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative Operations & Maintenance Cost	Retained Not Retained
No Action	No Action	No Action	No remedial actions taken.	Low No remedial actions are taken.	High	Low	Low	Not retained for further evaluation
ICs	ICs	Access and land use restrictions	Non-engineered instruments (e.g., administrative/legal) that help minimize the potential for human exposure to Cr(VI in groundwater and/or protect the integrity of the remedy.	High ICs would prevent the use of groundwater from the bedrock aquifer.	High	Low	Low	Retained for further evaluation as possible component of remedy
Monitoring	Monitoring	Monitoring	Monitoring of bedrock plume to track Cr(VI) plume growth and evaluate performance of other remedial actions. Typically combined with other actions that manage the source areas and mitigate exposure.	Moderate/High Monitoring is effective when used in conjunction with institutional controls or engineered passive or active remediation measures.	High	Low	Low/Moderate	Retained for further evaluation as possible component of remedy
	MNA	MNA	Relies on natural attenuation processes such as biological and chemical reduction, adsorption, dilution, and dispersion to manage Cr(VI) plumes. Monitors bedrock plume to track natural attenuation processes (primarily dilution and dispersion) until RAOs are achieved. Typically combined with other actions that manage the source areas and mitigate exposure. Contingent actions are identified in the event plume migration or risks exceed levels appropriate for MNA.	Low/Moderate There is significant uncertainty on the potential for MNA to be effective. Long-term Cr(VI) concentration trend data is not available to define if the bedrock plume is static or shrinking. In addition, the groundwater geochemistry is generally oxidizing and has relatively high pH, which limits abiotic reduction, microbial reduction, or sorption of the Cr(VI).	High	Low	Low/Moderate	Retained for further evaluation as possible component of remedy
Pump-and-Treat	Extraction	Groundwater Extraction System	Operation of groundwater extraction wells to remove Cr(VI) from bedrock aquifer. Groundwater is treated ex situ (e.g. using ion exchange or chemical precipitation) and discharged.	Moderate Groundwater extraction is only moderately effective for mass removal in dual porosity and complex fracture flow aquifers. Although groundwater in mobile fractures of the bedrock aquifer would be extracted, Cr(VI) in immobile groundwater residing in disconnected fracture networks would not be extracted.	Low/Moderate Installation of extraction wells and piping network would be limited by access restrictions and by high density of residential and commercial buildings. These access restrictions limit where groundwater can be extracted and increases likelihood that immobile groundwater will not be extracted.	Moderate	Moderate/High	Retained for further evaluation

TABLE 6-1
Focused Technology Screening for Hexavalent Chromium Treatment in Bedrock
Garfield Groundwater Contamination Superfund Site
Feasibility Study

General Response Actions	Remedial Technology	Process Option	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative Operations & Maintenance Cost	Retained Not Retained
In Situ Treatment	Chemical	In Situ Chemical Reduction	Subsurface delivery of chemical reductants (such as calcium polysulfide) within bedrock aquifer to stimulate reduction of Cr(VI).	Low Effective in reducing Cr(VI) to Cr (III) where chemicals contact groundwater. However, a majority of groundwater in the plume would not be treated due to relative short longevity of chemicals, and inaccessibility to immobile groundwater residing in disconnected fracture networks. Treatment effectiveness for mobile groundwater can be enhanced by combining injections with P&T, and/or increasing chemical dosage/injection frequency.	Moderate Would require a large number of injection wells. Does not require extensive piping system. Chemicals used for In situ reduction represent a handling and transport risk in high population density areas. Requires a large volume of water for injection.	Moderate/High Likely higher capital cost compared to In situ biological due to chemical costs and higher injection frequency.	High	Not retained for further evaluation in favor of in situ biological treatment
	Biological	In Situ Biological Treatment (Anaerobic)	Subsurface delivery of various organic substrates (such as EVO) within bedrock aquifer to stimulate anaerobic bioreduction of Cr(VI).	Low/Moderate Effective in reducing Cr(VI) to Cr(III) where sustained reducing zones can be established. However, immobile groundwater residing in disconnected fracture networks would not be treated effectively. Treatment effectiveness for mobile groundwater can be enhanced by combining injections with P&T, and/or increasing substrate dosage/injection frequency.	Moderate/High Would require a large number of injection wells. Does not require extensive piping system. Requires a large volume of water for injection.	Moderate/High	Moderate/High	Retained for further evaluation
	Physical	Flushing	Clean/treated water is injected to flush out Cr(VI) in groundwater to expedite remediation of bedrock aquifer. Would be a component of a pump-and-treat system.	Low/Moderate Flushing would not significantly increase the effectiveness of pump-and-treat systems due to inaccessibility of Cr(VI) in immobile groundwater residing in disconnected fracture networks. Increases likelihood of mounding in overburden and exacerbating basement infiltration.	Low/Moderate Installation of injection wells and piping network would be limited by access restrictions and by high density of residential and commercial buildings. These access restrictions limit where the plume can be flushed and increases likelihood that immobile groundwater will not be flushed.	Moderate	Moderate/High	Does not significantly enhance pump-and-treat, not retained for further evaluation

Notes:
Cr(VI) - hexavalent chromium
Cr(III) - trivalent chromium
EVO - emulsified vegetable oil
ICs - institutional controls

TABLE 7-1

Alternative Design Parameters

Garfield Groundwater Contamination Superfund Site

Feasibility Study

Design Component	Alternative 2A: Source Treatment (Soil Mixing)	Alternative 2B: Source Treatment (In Situ Injection)	Alternative 3: Source Treatment and In Situ Reduction Barriers for Overburden	Alternative 4: Source Treatment and Pump & Treat for Overburden	Alternative 5: Source Treatment, and Combined In Situ Reduction and Pump & Treat for Overburden
Source Treatment (ECE Property)					
Source Soil Mixing					
Area (sf)	18,000				
Depth (ft)	19				
Unsaturated volume (CY)	8,000				
Saturated volume (CY)	4,667				
Calcium polysulfide (30 wt%) (lbs)	672,269				
Source Injections					
Injection wells (20 ft deep)		45	45	45	45
Saturated volume (CY)		4,667	4,667	4,667	4,667
Calcium polysulfide (30 wt%) (lbs)		224,090 (year 0, 1, 2, 3, 4, 5, and 6)	224,090 (year 0, 1, 2, 3, 4, 5, and 6)	224,090 (year 0, 1, 2, 3, 4, 5, and 6)	224,090 (year 0, 1, 2, 3, 4, 5, and 6)
Pump-and-Treat System					
Extraction wells (45 ft deep)	3	3	3	3	3
Reinjection wells (45 ft deep)	6	6	6	6	6
Monitoring wells (45 ft deep)	4	4	4	4	4
EVO (60%) injection events	3 (year 0, 3, 6)	3 (year 0, 3, 6)	3 (year 0, 3, and 6)	3 (year 0, 3, and 6)	3 (year 0, 3, and 6)
EVO (60%) per event (lbs)	33,936	33,936	33,936	33,936	33,936
Operation timeframe (years)	6	6	6	6	6
Overburden Plume Treatment					
In Situ Reduction Barriers					
Injection wells (50 ft deep)			290		290
EVO (60%) injection events			7 (year 0, 3, 6, 10, 15, 20, and 25)		7 (year 0, 3, 6, 10, 15, 20, and 25)
EVO (60%) per event (lbs)			1,640,240		1,640,240
Monitoring wells			6		6
Operation timeframe (years)			30		30
Pump-and-Treat System					
Extraction wells				14	14
Monitoring wells				6	
Operation timeframe (years)				30	30
Basement Remediation					
Dewatering, Cleaning, Waterproofing					
Inspections per year	5	5	5	5	5
Remedial Actions per year	2	2	2	2	2
Operation timeframe (years)	20	20	20	20	20

Notes:

% - percent

CY - cubic yards

ECE - E.C. Electroplating, Inc.

EVO - emulsified vegetable oil

ft - feet

lbs - pounds

sf - square ft

wt% - percent by weight

TABLE 7-2

Summary of CERCLA Criteria

Garfield Groundwater Contamination Superfund Site

Feasibility Study

Threshold Criteria	
Overall Protection of Human Health and the Environment (HHE)	Human health groundwater risk management Ecological surface water risk management Human health direct exposure risk management (basement residue) Soil to groundwater/surface water pathway risk management Draws on assessments conducted under other criteria, especially long-term effectiveness, short-term effectiveness, and ARARs
Compliance with ARARs	Chemical-specific ARARs Action-specific ARARs Location-specific ARARs Compliance with other criteria, advisories, and guidance
Balancing Criteria	
Long-Term Effectiveness and Permanence	Magnitude of residual risk Adequacy and reliability of controls
Reduction of Toxicity, Mobility, or Volume (TMV) through Treatment	Amount of hazardous materials destroyed or treated Degree of expected reduction in TMV Degree to which treatment is irreversible Type and quantity of residuals remaining after treatment
Short-Term Effectiveness	Protection of community during remedial actions Protection of workers during remedial actions Environmental impacts, including sustainability considerations Time until RAOs are achieved
Implementability	Ability to construct, operate, and monitor the technology Reliability of the technology Ease of undertaking additional remedial action, if necessary Ability to monitor the remedy's effectiveness Ability to coordinate and obtain approvals from other agencies Availability of equipment, specialists, prospective technologies, offsite treatment, storage or disposal services, and capacity
Cost	Capital costs Annual O&M costs Total present worth cost of all capital, annual O&M, and periodic costs (net present value) Total nondiscounted cost all capital, annual O&M, and periodic costs
Modifying Criteria	
State Acceptance*	Indicates whether the state concurs with, opposes, or has no comment on the preferred alternative
Community Acceptance*	Assesses the public response to the preferred alternative. Although public comment is an important part of the decision-making process, EPA is required by law to balance community concerns with the above criteria.

Notes:

* These criteria are not assessed in this report.

ARARs - applicable or relevant and appropriate requirements
CERCLA - Comprehensive Environmental Response, Compensation and Liability Act of 1980
HHE - human health and the environment
O&M - operation and maintenance
RAO- remedial action objectives
TMV - toxicity, mobility, or volume

TABLE 7-3

Remedial Alternatives Overburden Cleanup Timeframes

Garfield Groundwater Contamination Superfund Site

Feasibility Study

Alternative	Time to 90% Area Reduction in Overburden (Years)	Time to Complete Remediation* in Overburden (Years)
Alternative 1: No Further Action	210	270
Alternative 2: Source Treatment	180	220
Alternative 3: Source Treatment and In situ Reduction for Overburden	111	177
Alternative 4: Source Treatment and Pump and Treat for Overburden	117	174
Alternative 5: Source Treatment, and Combined Pump and Treat and In situ Reduction for Overburden	84	144

Notes:

* "Complete Remediation" is defined for this purpose as all model cells representing the geologic unit having less than 70 µg/L of hexavalent chromium concentration.

TABLE 7-4

Alternative Analysis Screening Against NCP Criteria

Garfield Groundwater Contamination Superfund Site

Feasibility Study

	Alternative 1 **No Further Action**	**Alternative 2A** **Source Treatment (Soil Mixing)**	**Alternative 2B** **Source Treatment (In situ Injection)**	**Alternative 3** **Source Treatment and In Situ Reduction Barriers for Overburden**	**Alternative 4** **Source Treatment and Pump and Treat for Overburden**	**Alternative 5** **Source Treatment and Pump and Treat with In situ Reduction for Overburden**
Threshold Criteria						
Overall Protection of Human Health and the Environment (HHE)	1 -Not protective since it allows for potential exposure to chromium through basement infiltration and future use of the aquifer. -Allows for unmonitored, potential further migration of groundwater contaminants.	3 -Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to chromium. -Source zone treatment would address the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period, but a longer period compared to Alternatives 3, 4, or 5.	3 -Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to chromium. -Source zone treatment would mitigate the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period, but a longer period compared to Alternatives 3, 4, or 5.	3 -Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to chromium. -Source zone treatment would mitigate the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period.	4 -Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to chromium. -Source zone treatment would mitigate the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period.	4 -Expected to be protective of human health and the environment. -Basement inspections and cleaning would mitigate human exposure to chromium. -Source zone treatment would mitigate the overburden plume source and treat the highest mass of Cr(VI) concentrations in the plume. -Monitoring can track progress and compliance with RAOs. -ICs would be used to help control human exposure to groundwater until PRGs are achieved. -PRGs would be achieved over an extended time period, but the shortest of any of the alternatives.
Compliance with ARARs	1 -Since there is no action, ARARs for the source area and overburden plumes would not be met within a reasonable timeframe. -Based on groundwater modeling, achievement of the ARARs in the overburden plume would take hundreds of years.	2 -Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -Attenuation of the overburden plume is expected to occur through primarily dilution and dispersion. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.	2 -Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -Attenuation of the overburden plume is expected to occur through primarily dilution and dispersion. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.	3 -Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -In situ reduction barriers would be designed and implemented to eventually meet overburden plume PRGs. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.	3 -Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -Pump and treat would be designed and implemented to eventually meet overburden plume PRGs. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.	3 -Source remediation activities are expected to support the eventual achievement of the overburden plume PRGs. -Pump and treat combined with in situ reduction barriers would be designed and implemented to eventually meet overburden plume PRGs. Based on groundwater modeling, achievement of the overburden plume PRG is expected to take more than 100 years.
Balancing Criteria						
Long-Term Effectiveness and Permanence	N/A Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	2 *Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps and sealants. -This alternative would permanently achieve PRGs in the overburden plume through dilution and dispersion. *Factors that may provide disadvantages in the long-term:* -Cr(VI) in poorly connected pores and immobile zones may delay achieving of PRGs within certain portions of the plume. -Long-term monitoring would be required for the groundwater plume. -Long-term enforcement of ICs would be required to mitigate risk.	2 *Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps and sealants. -This alternative would permanently achieve PRGs in the overburden plume through dilution and dispersion. *Factors that may provide disadvantages in the long-term:* -Cr(VI) residing in poorly connected pores and immobile zones may result in difficult achievement of PRGs within certain portions of the plume. -Long-term monitoring would be required for groundwater plume. -Long-term enforcement of ICs would be required to mitigate risk.	3 *Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -In situ reduction would permanently achieve PRGs in the overburden plume by reduction of Cr(VI) to Cr(III). -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps and sealants. *Factors that may provide disadvantages in the long-term:* -Rebound due to Cr(VI) in poorly connected pores and immobile zones would likely occur once injections are completed. -Long-term monitoring would be required to evaluate the long-term effectiveness of remediation in the groundwater plume. -Long-term enforcement of ICs would be required to mitigate risk.	3 *Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -Pump and Treat would achieve PRGs in the overburden plume by removing Cr(VI) from the groundwater and ex situ treatment. -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps and sealants. *Factors that may provide disadvantages in the long-term:* -Rebound due to Cr(VI) in poorly connected pores and immobile zones would likely occur once pumping stops. -Pumps would need to be repaired/replaced and wells would need to be rehabilitated routinely to maintain mass removal. -Long-term monitoring would be required to evaluate the long-term effectiveness of remediation in the groundwater plume. -Long-term enforcement of ICs would be required to mitigate risk.	4 *Factors expected to perform well in the long-term:* -Source zone treatment would permanently reduce Cr(VI) mass in the source overburden and shallow bedrock. -Pump and Treat with in situ reduction would achieve RAOs in the overburden plume through both reduction of Cr(VI) to Cr(III), and removal of Cr(VI) from groundwater and ex situ treatment. -Basement monitoring would achieve RAOs at impacted properties through French drains, sump pumps and sealants. *Factors that may provide disadvantages in the long-term:* -Rebound due to Cr(VI) in poorly connected pores and immobile zones would likely occur once pumping stops. -Pumps would need to be repaired/replaced and wells would need to be rehabilitated routinely to maintain mass removal. -Long-term monitoring would be required to evaluate the long-term effectiveness of remediation in the groundwater plume. -Long-term enforcement of ICs would be required to mitigate risk.
Reduction of Toxicity, Mobility, or Volume (TMV) through Treatment	N/A Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	2 -Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -Reduction in toxicity and volume of the plume is achieved primarily through dilution and dispersion as groundwater flows downgradient.	2 -Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -Reduction in toxicity and volume of the plume is achieved primarily through dilution and dispersion as groundwater flows downgradient.	3 -Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -In situ reduction would permanently reduce Cr(VI) in the plume, reducing both toxicity and mobility.	3 -Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -Pump and treat would permanently remove Cr(VI) in the plume, reducing toxicity and volume.	4 -Source zone treatment would reduce toxicity and mobility of Cr(VI) in the source zone. -In situ reduction would permanently reduce Cr(VI) in the plume, reducing both toxicity and mobility. -Pump and treat would permanently remove Cr(VI) in the plume, reducing toxicity and volume.

TABLE 7-4

Alternative Analysis Screening Against NCP Criteria

Garfield Groundwater Contamination Superfund Site

Feasibility Study

	Alternative 1 No Further Action	Alternative 2A Source Treatment (Soil Mixing)	Alternative 2B Source Treatment (In situ Injection)	Alternative 3 Source Treatment and In Situ Reduction Barriers for Overburden	Alternative 4 Source Treatment and Pump and Treat for Overburden	Alternative 5 Source Treatment and Pump and Treat with In situ Reduction for Overburden
Short-Term Effectiveness	N/A	3	3	3	4	3
	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	*Factors expected to perform well in the short-term:* -Soil mixing would remediate source area overburden within one year. -Fewer impacts on the community and risks to workers would be expected, since no active remediation would be implemented outside source area. *Factors that may provide disadvantages in the short-term:* -There is possible risk to workers dealing with hazardous chemicals during source treatment. -Excavation, stockpiling, and soil mixing would require heavy equipment on the ECE property which would cause noise and air pollution and could be disruptive to the surrounding community. -GHG are primarily generated during equipment operation and long-term transportation of large quantities of substrate. -No active treatment in the overburden plume would limit short term effectiveness.	*Factors expected to perform well in the short-term* : -In situ reduction within the source area overburden and shallow bedrock would become effective at reducing Cr(VI) to Cr(III) once reducing conditions are established in the subsurface following initial injections. - Fewer impacts on the community and risks to workers would be expected, since no active remediation would be implemented outside source area. *Factors that may provide disadvantages in the short-term:* - In situ injections would remediate source area overburden, but may require multiple injections over approximately 6 years to maintain reagent distribution. -GHG are primarily generated during source zone treatment, well installation, and long-term transportation of large quantities of substrate. -There is possible risk to workers dealing with hazardous chemicals during source treatment. -No active treatment in the overburden plume would limit short term effectiveness.	*Factors expected to perform well in the short-term:* -In situ reduction within the source area overburden and shallow bedrock would become effective at reducing Cr(VI) to Cr(III) once reducing conditions are established in the subsurface following initial injections. *Factors that may provide disadvantages in the short-term:* -90% reduction of the overburden plume area would take more than 100 years, providing little short term effectiveness. -More disruptions to surrounding community would occur due to installation of over 200 injection wells. -GHG are primarily generated during source zone treatment, well installation, and long-term transportation of large quantities of substrate. -There is possible risk to workers dealing with hazardous chemicals during source overburden treatment. -The mobilization of reduced metals (e.g., iron, manganese, and arsenic) in the aquifer would need to be considered and monitored during implementation of the in situ reduction barriers.	*Factors expected to perform well in the short-term:* -In situ reduction within the source area overburden and shallow bedrock would become effective at reducing Cr(VI) to Cr(III) once reducing conditions are established in the subsurface following initial injections. -Less disruptions to surrounding community would occur during installation of pump and treat system compared to installing in situ injection wells. *Factors that may provide disadvantages in the short-term:* -90% reduction of the overburden plume area would take more than 100 years, providing little short term effectiveness. -GHG are primarily generated during source zone treatment and operation of groundwater treatment system. -There is possible risk to workers dealing with hazardous chemicals during source overburden treatment.	*Factors expected to perform well in the short-term:* -In situ reduction within the source area overburden and shallow bedrock would become effective at reducing Cr(VI) to Cr(III) once reducing conditions are established in the subsurface following initial injections. *Factors that may provide disadvantages in the short-term:* -Active treatment in the groundwater overburden would result in 90% reduction of the overburden plume area within 90 years, providing the best option, but still little short term effectiveness. -More disruptions to surrounding community would occur due to installation of over 200 injection wells. -GHG are primarily generated during source zone treatment, well installation, long-term transportation of large quantities of substrate, and operation of groundwater treatment system. -There is possible risk to workers dealing with hazardous chemicals during source overburden treatment. -The mobilization of reduced metals (e.g., iron, manganese, and arsenic) in the aquifer would need to be considered and monitored during implementation of the in situ reduction barriers.
Implementability	N/A	4	4	2	3	2
	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	*Factors expected to perform well for implementation:* -Conventional equipment and vendors could be used for implementation of active treatment elements. -All above ground structures on the ECE property have been removed. -No offsite active treatment would be performed within the overburden plume, resulting in little disturbance to the community. *Factors that may provide disadvantages for implementation:* -Source soil mixing actions may be constrained due to the limited space within the ECE property and site traffic control issues.	*Factors expected to perform well for implementation:* -Conventional equipment and vendors could be used for implementation of active treatment elements. -All above ground structures on the ECE property have been removed. -No offsite active treatment would be performed within the overburden plume, resulting in little disturbance to the community.	*Factors expected to perform well for implementation:* -Conventional equipment and vendors could be used for implementation of active treatment elements. *Factors that may provide disadvantages for implementation:* -Community would be disturbed over a large area due to installation of over 200 injection wells, and transport, delivery, an storage of large amounts of substrate for ongoing injections. -Construction period would be extended due to the number of injection wells to be installed. -Right of Way permits would be required for well installation and multiple injection events from the City of Garfield.	*Factors expected to perform well for implementation:* -Conventional equipment and vendors could be used for implementation of active treatment elements. *Factors that may provide disadvantages for implementation:* -Community would be disturbed over a large area due to installation of pump and treat system piping and wells. -Right of Way permits would be required for well installation from the City of Garfield. -Permits would be required for discharge of treated water.	*Factors expected to perform well for implementation:* -Conventional equipment and vendors could be used for implementation of active treatment elements. *Factors that may provide disadvantages for implementation:* -Community would be disturbed over a large area due to installation of over 200 injection wells, and pump and treat system piping and wells, and transport, delivery, and storage of large amounts of substrate for ongoing injections. -Construction period would be extended due to the number of injection wells to be installed. -Right of Way permits would be required for well installation and multiple injection events from the City of Garfield. -Permits would be required for discharge of treated water.
Cost	$0	$13,937,000	$10,197,000	$37,334,000	$22,088,000	$49,112,000

Notes:

1 - Alternative does not meet the criterion and has disadvantages or uncertainty.
2 - Alternative is expected to perform poorly against the criterion and may have disadvantages or uncertainty.
3 - Alternative is expected to perform moderately well against the criterion but with some disadvantages or uncertainty.
4 - Alternative is expected to perform well against the criterion with few to no apparent disadvantages or uncertainty.
5 - Alternative is expected to perform very well against the criterion with no apparent disadvantages or uncertainty.

ARARs - applicable or relevant and appropriate requirements
Cr(VI) - hexavalent chromium
Cr(III) - trivalent chromium
ECE - E.C. Electroplating, Inc.
GHG - greenhouse gas
HHE - human health and the environment

ICs - institutional controls
N/A - not applicable
NCP - National Oil and Hazardous Substance Pollution Contingency Plan
PRG - preliminary remediation goal
RAO - remedial action objective
TMV - toxicity, mobility, or volume

TABLE 7-5

Remedial Alternative Present Value Cost Estimates

Garfield Groundwater Contamination Superfund Site

Feasibility Study

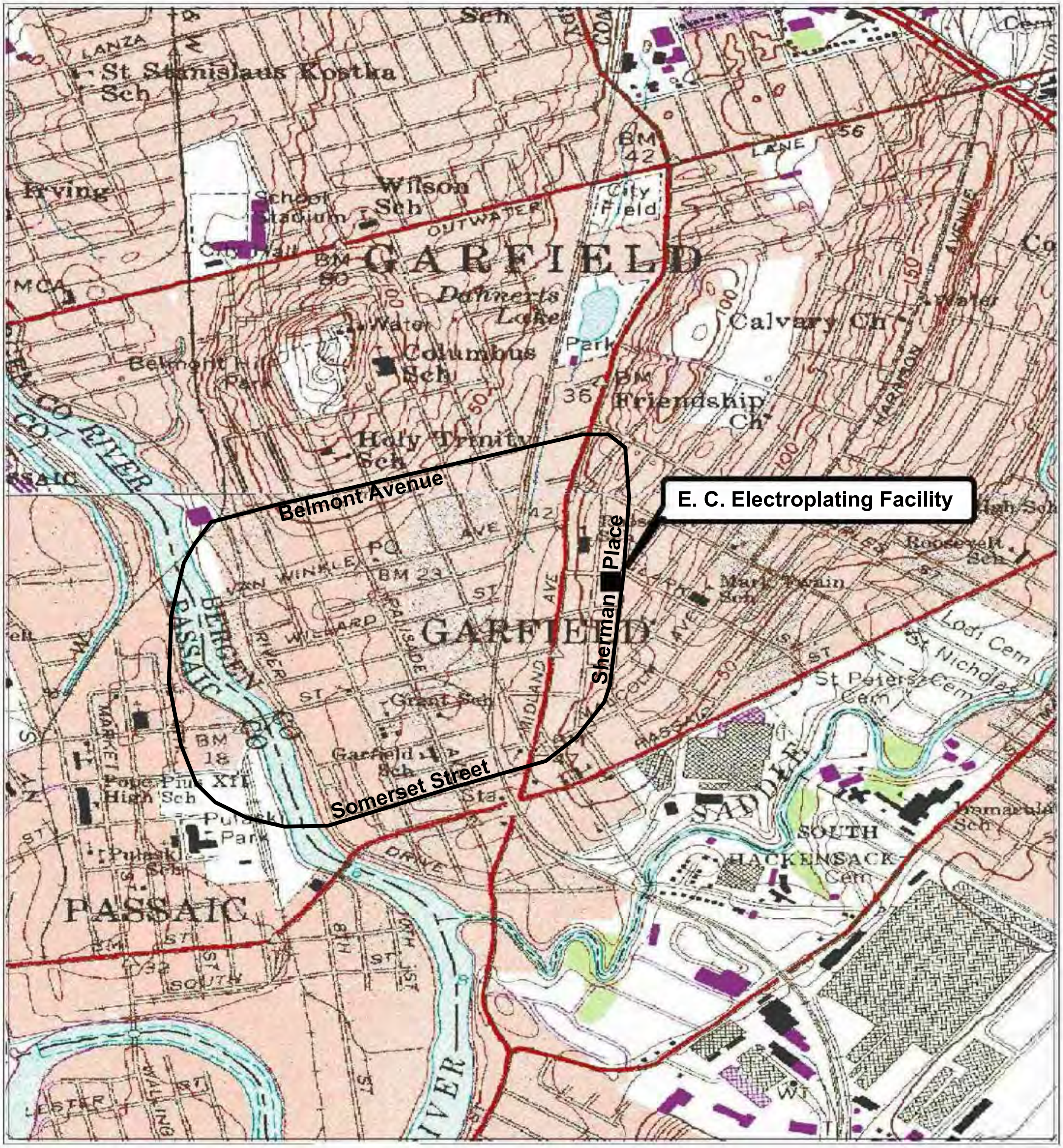
Alternative	Capital Cost	O&M NPV Cost	Total NPV Cost
Alternative 2A: Source Treatment (Soil Mixing)	\$8,035,000	\$5,902,000	\$13,937,000
Alternative 2B: Source Treatment (In Situ Injection)	\$3,263,000	\$6,934,000	\$10,197,000
Alternative 3: Source Treatment and In situ Reduction for Overburden	\$14,096,000	\$23,238,000	\$37,334,000
Alternative 4: Source Treatment and Pump and Treat for Overburden	\$5,170,000	\$16,918,000	\$22,088,000
Alternative 5: Source Treatment, and Combined Pump and Treat and In Situ Reduction for Overburden	\$15,892,000	\$33,220,000	\$49,112,000

Notes:

NPV - net present value

Cost estimate details are provided in Appendix D.

Figures



Legend

Approximate Site Boundaries

Magnetic North

1,500 0 1,500 Feet

Map created using USGS 1:24,000 Topographic Map, Hackensack and Weehawken Quadrangles, Datum NAD27; Contour Interval = 10 Feet

Figure 1-1
Site Location Map
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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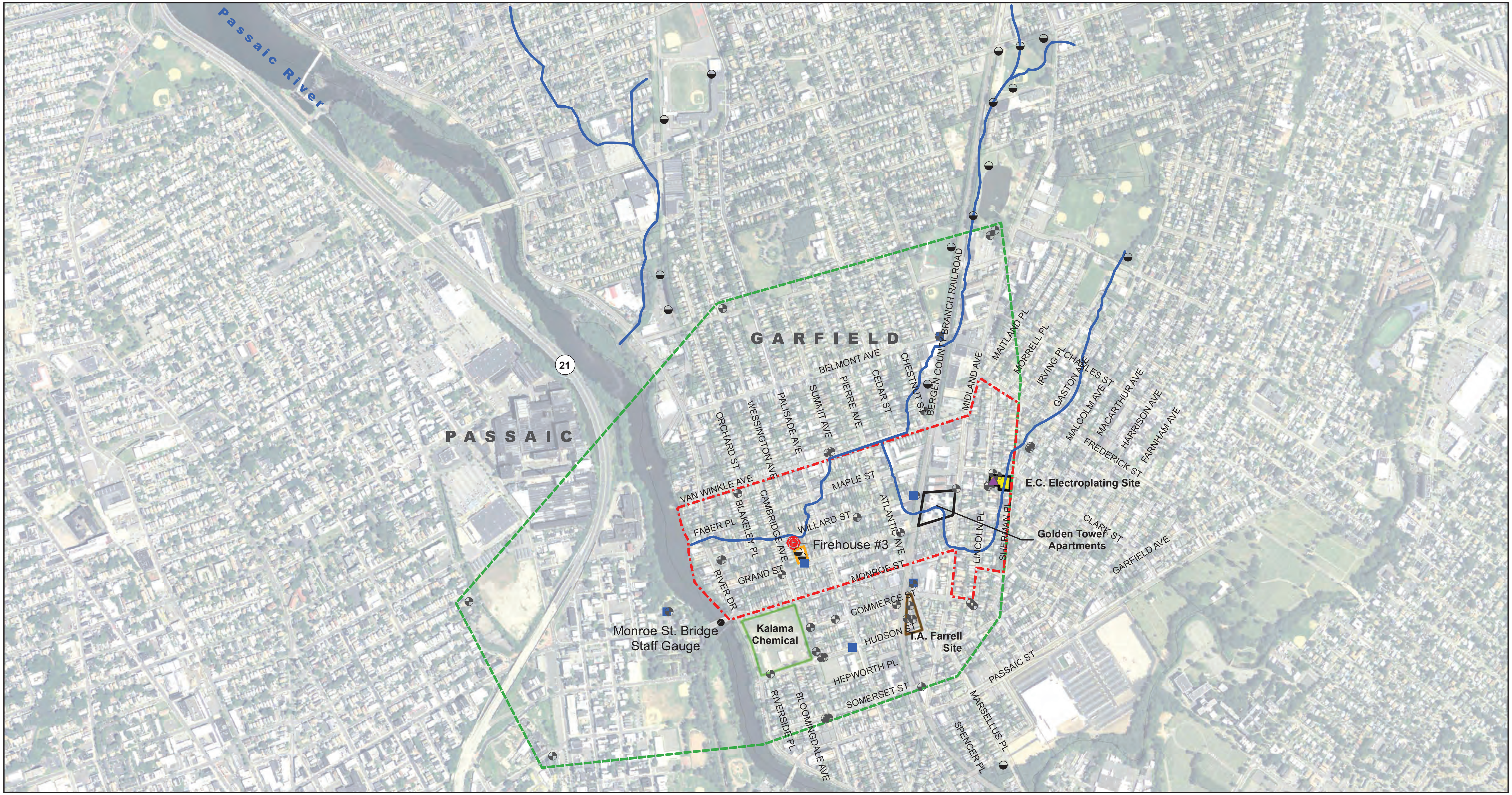

- Monroe St. Bridge Staff Gauge
- Former Industrial Well
- Former Garfield Municipal Wells (Approximate Locations)
- Multiport FLUTe Well
- Conventional Monitoring Well
- Firehouse #3
- Approximate Location of Historical Stream (1910 Tax Map)
- Basement Study Area & 2011 Groundwater Study Area Boundaries
- Present Groundwater Study Area Boundaries
- Golden Tower Apartments
- Staging Area
- Kalama Chemical Site
- E.C. Electoplating Site (125 Clark St., Garfield, NJ)
- T.A. Farrell Site

NOTES:

New Jersey State Plane Coordinate system
Horizontal Datum NAD83, Vertical Datum NAVD88
US Survey Feet
Imagery Source: National Aerial Imagery Program
Imagery Date: 2010

N

Feet
0 500 1,000 1,500 2,000

Figure 1-2
Site Plan
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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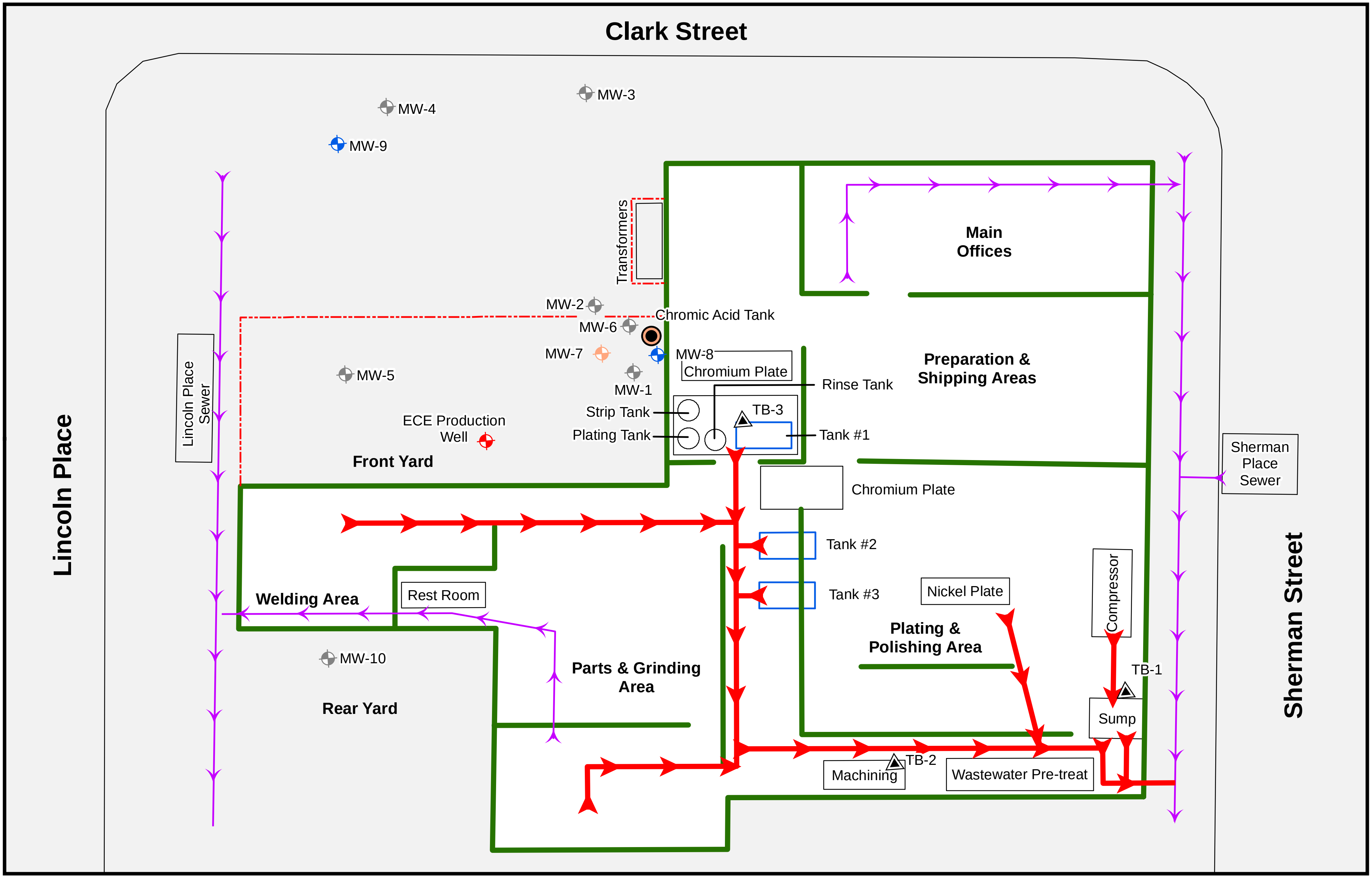
V:\PROJECTS\C156 GARFIELD\FIGURES\20140303\FIGURE 1-2.MXD JGAINES



Legend

- Process Wastewater Flow
- Sanitary Wastewater Flow
- Fence
- Building Wall
- Abandoned Recovery Well
- Abandoned Monitoring Well
- ECE Production Well
- Monitoring Well
- Chromic Acid Tank
- Soil Sampling Location
- Chromic Acid Vertical Storage Tank

NOTE:
Site dimensions are approximately 200' X 150' (0.65 acre)

NOT TO SCALE

Figure 1-3

Former E.C. Electroplating Facility Layout
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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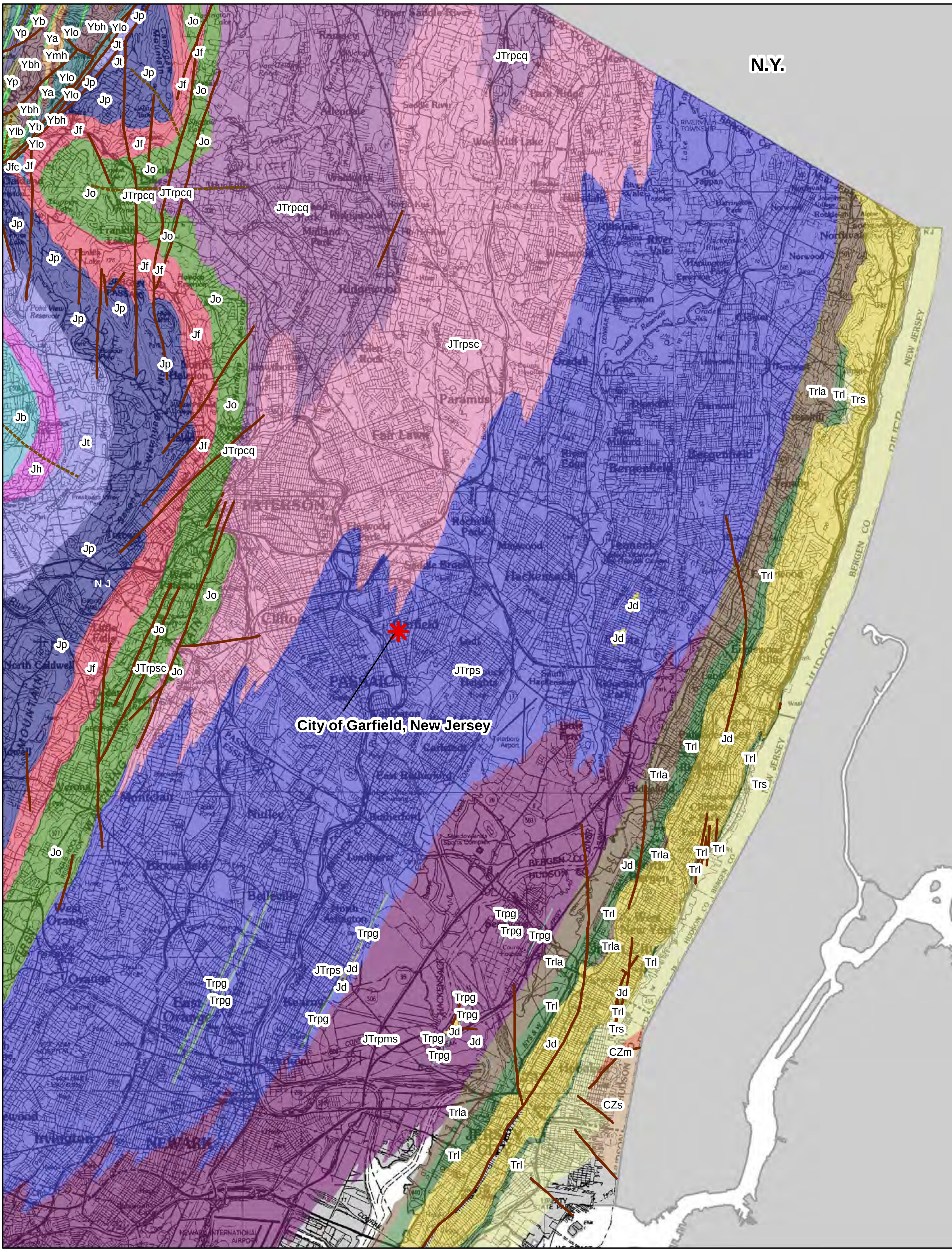


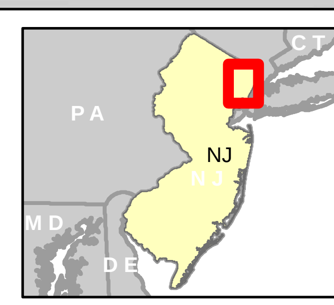
- dikes
- faults
- folds

Bedrock Geology

- CZm, Manhattan Schist
- CZs, Serpentinite
- JTrpcq, Passaic Formation Quatzite-clast Conglomerate facies
- JTrpms, Passaic Formation Mudstone facies
- * JTrps, Passaic Formation Sandstone and Siltstone facies
- JTrpsc, Passaic Formation Conglomerate and Sandstone facies
- Jb, Boonton Formation
- Jd, Jurassic Diabase
- Jf, Feltville Formation
- Jfc, Feltville Formation Conglomerate and Sandstone facies
- Jh, Hook Mt. Basalt
- Jo, Orange Mountain Basalt
- Jp, Preakness Basalt
- Jt, Towaco Formation
- Omb, Bushkill Member
- Trl, Lockatong Formation
- Trla, Lockatong Formation Arkosic Sandstone facies
- Trpg, Passaic Formation Gray bed
- Trs, Stockton Formation
- Ya, Amphibolite
- Yb, Biotite-Quartz-Feldspar Gneiss
- Ybh, Hornblende Granite
- Yk, Potassic Feldspar Gneiss
- Ylb, Biotite-Quartz-Oligoclase Gneiss
- Ylo, Quartz-Oligoclase Gneiss
- Ymh, Hornblende-Quartz-Feldspar Gneiss
- Yp, Pyroxene Gneiss

NOTES:

New Jersey State Plane Coordinate System
Horizontal Datum NAD83, Vertical Datum NAVD88
US Survey Feet
Data Source: New Jersey Department of Environmental Protection, NJ-GeoWeb



Miles
0 1 2 3 4
N

Figure 1-4
Regional Bedrock Geology
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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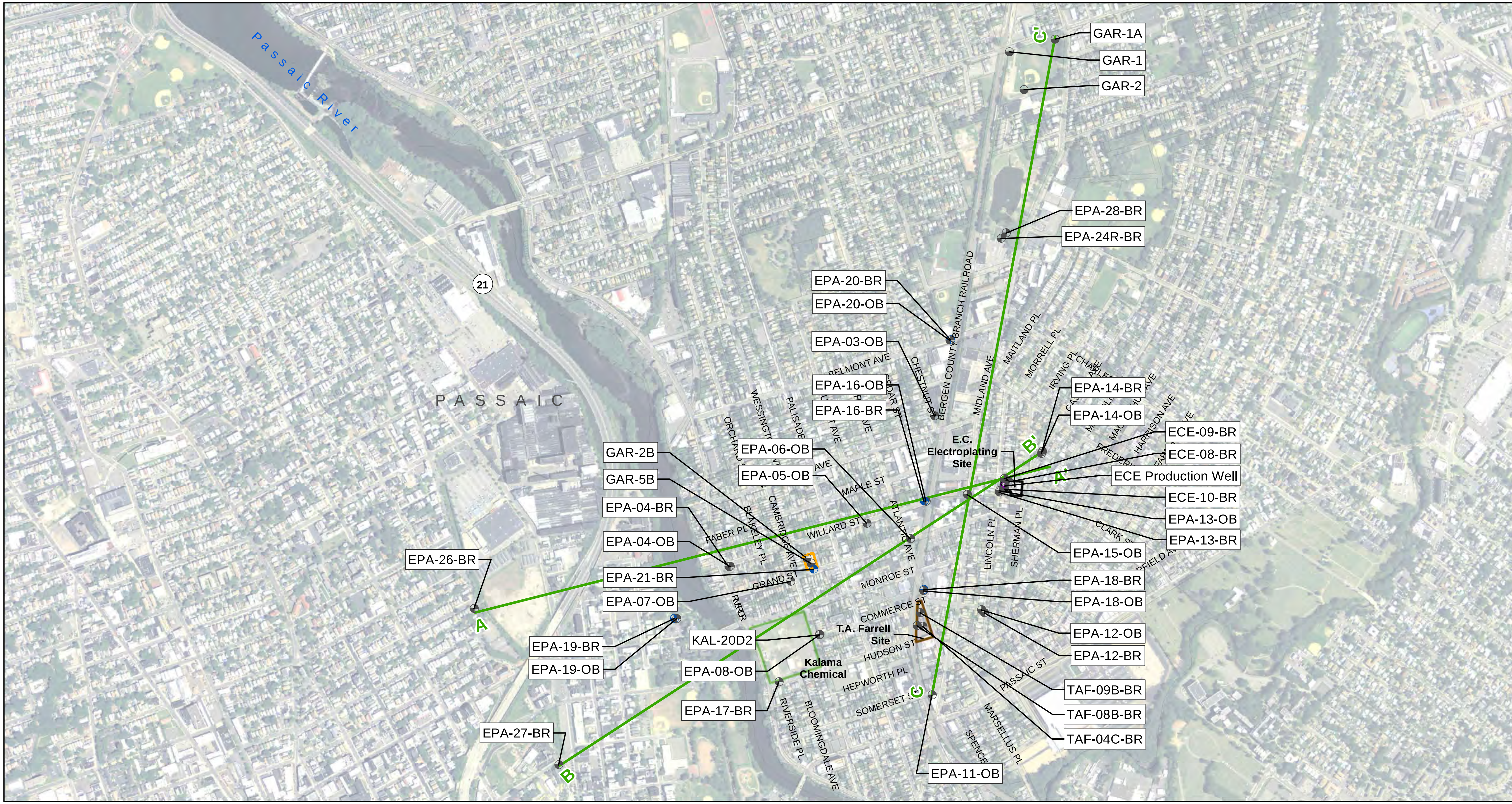
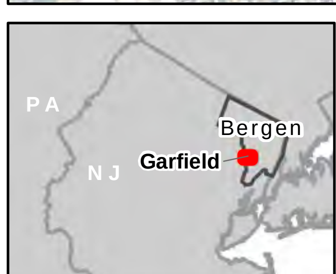
V:\PROJECTS\C156 GARFIELD\FIGURES\FIGURE 3-1.MXD JGAINES





- ECE Production Well
- Former Garfield Municipal Well
- Multiport FLUTe Well
- Conventional Monitoring Well
- Cross Section Line
- Staging Area
- Kalama Chemical Site
- E.C. Electoplating Site (125 Clark St., Garfield, NJ)
- T.A. Farrell Site

Feet

0 500 1,000 2,000

NOTES:

New Jersey State Plane Coordinate System
Horizontal Datum NAD83, Vertical Datum NAVD88
US Survey Feet
Monitoring wells not included in cross section are not shown
Imagery Source: National Aerial Imagery Program
Imagery Date: 2010

Figure 1-5
Cross Section Location Map
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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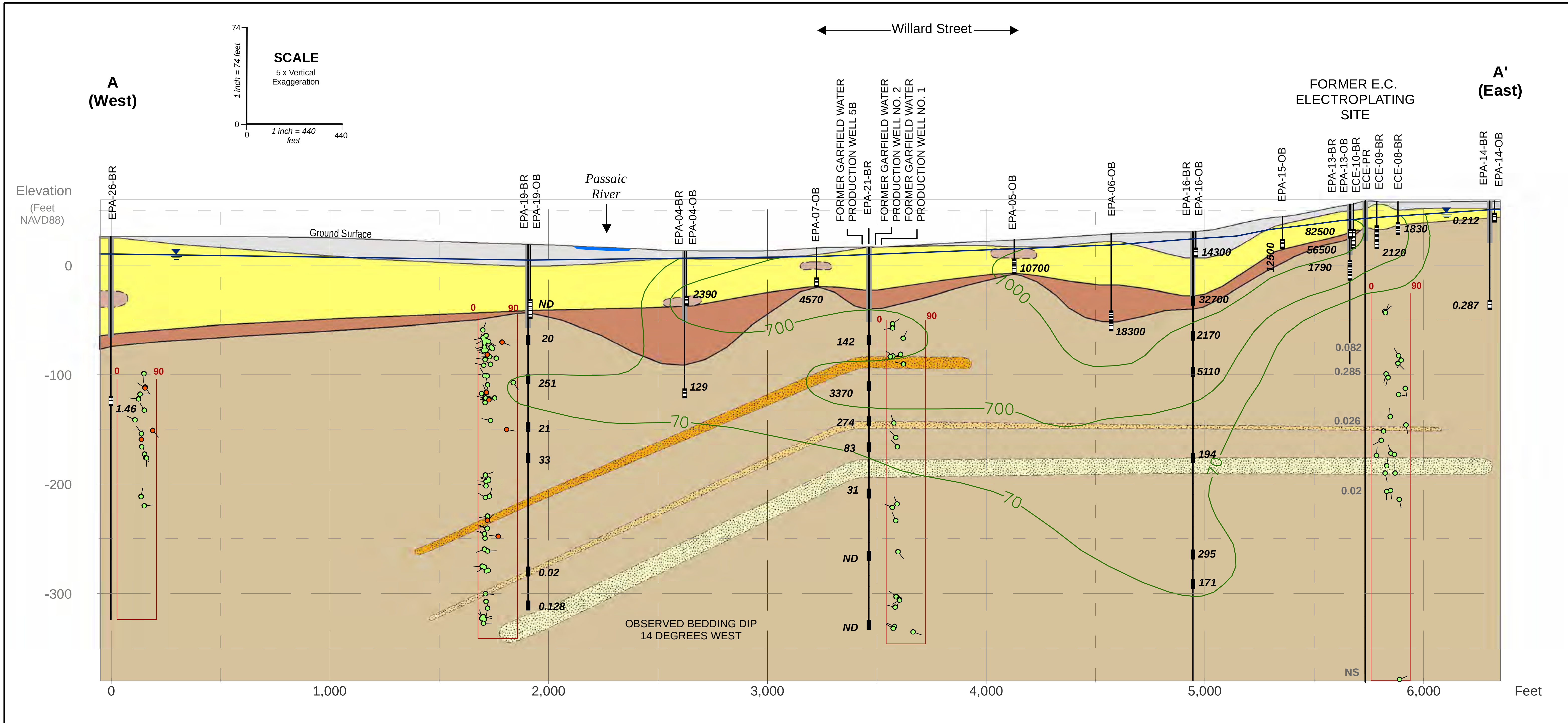
V:\PROJECTS\C156 GARFIELD\FIGURES\20140303\FIGURE 3-2.MXD JGAINES

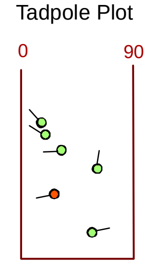


Legend

- Potentiometric Groundwater Surface
- FLUTe Monitoring Port Interval
- Conventional Monitoring Well Screened Interval
- Extent of Isolation Casing
- -0.02 Unvalitdated Packer Testing Result
- 5110 Hexavalent Chromium Concentration (ppb) (2012 RI Groundwater Sampling Event #1 and 2013 RI Groundwater Sampling Event)
- Depth of Borehole Drilling
- Hexavalent Chromium Isoconcentration Contour (ppb)
- Inferred Hexavalent Chromium Isoconcentration Contour (ppb)

- Sand/Gravel
- Silt/Clay
- Upper Sandstone
- Lower Sandstone
- Middle Sandstone
- Fill Soils (Inferred in Borings Where Not Logged)
- Weathered Bedrock
- Interbedded Mudstone Siltstone Sandstone

Tadpole Plot



Circle position indicates dip angle. Tail points in azimuth direction: up for north, down for south, right for east, left for west

- Fracture/Feature
- Hairline Fracture

Applicable Regulatory Criteria:

	Criteria
Analyte	New Jersey Department of Environmental Protection - Groundwater Quality Criteria (July 2010)
Cr, VI	*70 ppb

** New Jersey Department of Environmental Protection Groundwater Quality Standards Class IIA Constituent Value for total chromium is being used as a reference for hexavalent chromium.*

Notes/Definitions:

1. The potentiometric groundwater surface is based on measurements collected August 7, 2012.
2. Elevations are in units of feet referenced to the 1988 North American Vertical Datum (NAVD88).
3. United States Environmental Protection Agency (USEPA) overburden borings were advanced using rotasonic drilling technology and hollow stem augers. Soil and rock were logged continuously from 10-foot cored intervals.
4. USEPA bedrock borings were advanced using rotary air hammer drilling technology. Soil and rock were logged in 5 to 10 foot intervals from cuttings brought to the surface during drilling.
5. Borings within the E.C. Electroplating site (ECE) were installed in 1999 by Chapin Engineering using rotary air hammer drilling technology.
6. ppb = parts per billion
7. Cr, VI = hexavalent chromium.
8. NJGS = New Jersey Geological Survey.
9. The depictions of the former Garfield water production wells are based on information obtained from New Jersey well permits. Detailed logs are not available.
10. Bedrock wells EPA-16-BR and ECE-PR-BR boreholes extend deeper than 350 ft msl and are truncated on this figure.

Figure 1-6

Geologic Cross-Section A - A'

Feasibility Study Report

Garfield Groundwater Contamination Superfund Site

Garfield, NJ 07026

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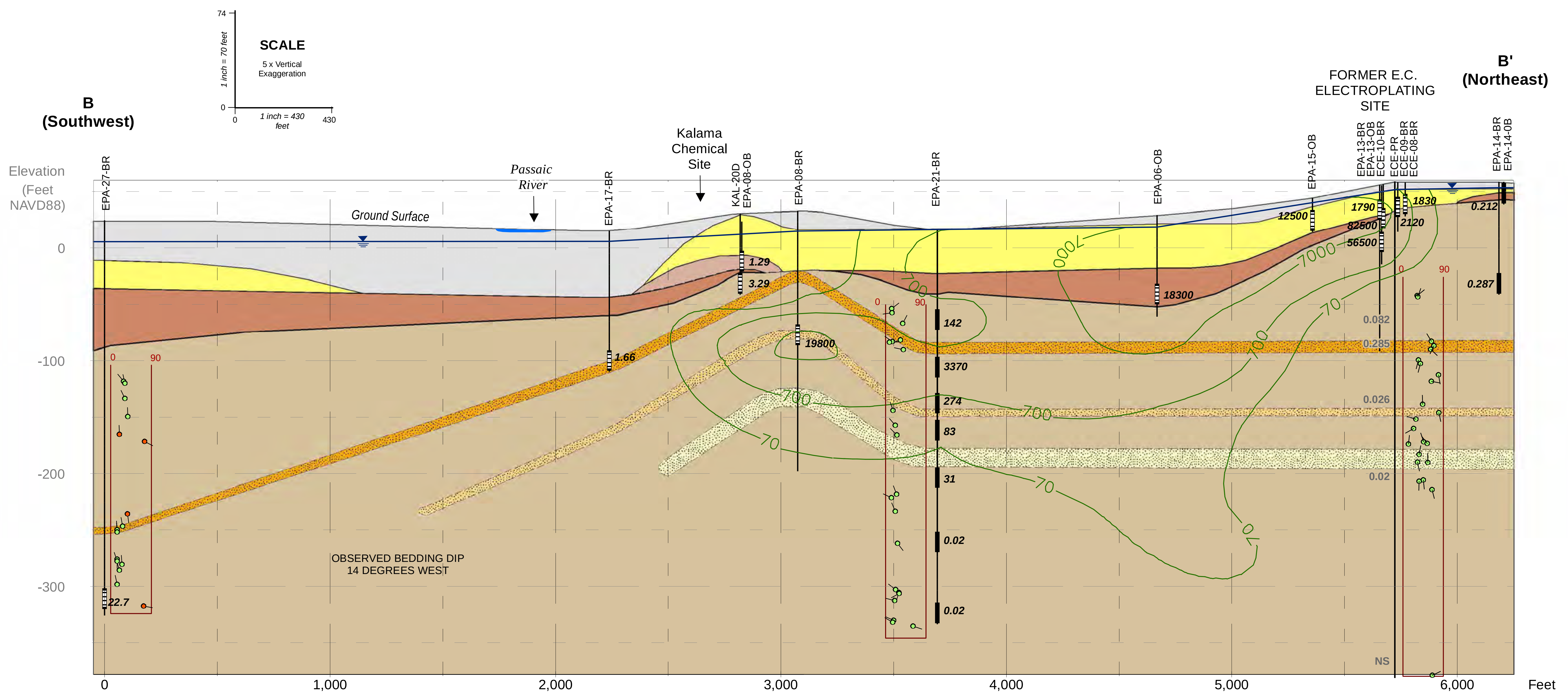

Legend

- Potentiometric Groundwater Surface
- FLUTe Monitoring Port Interval
- Conventional Monitoring Well Screened Interval
- Extent of Isolation Casing
- 0.02 Unvalidated Packer Testing Result
- 5110 Hexavalent Chromium Concentration (ppb) (2012 RI Groundwater Sampling Event #1 and 2013 Groundwater Sampling Event)
- Depth of Borehole Drilling
- Hexavalent Chromium Isoconcentration Contour (ppb)
- Inferred Hexavalent Chromium Isoconcentration Contour (ppb)
- Sand/Gravel
- Silt/Clay
- Upper Sandstone
- Lower Sandstone
- Middle Sandstone
- Fill Soils (Inferred in Borings Where Not Logged)
- Weathered Bedrock
- Interbedded Mudstone Siltstone Sandstone

Tadpole Plot

0 90

Circle position indicates dip angle. Tail points in azimuth direction: up for north, down for south, right for east, left for west

- Fracture/Feature
- Hairline Fracture

Applicable Regulatory Criteria:

Analyte	Criteria: New Jersey Department of Environmental Protection - Groundwater Quality Criteria (July 2010)
Cr, VI	*70 ppb

** New Jersey Department of Environmental Protection Groundwater Quality Standards Class IIA Constituent Value for total chromium is being used as a reference for hexavalent chromium.*

Notes/Definitions:

1. The potentiometric groundwater surface is based on measurements collected August 7, 2012.
2. Elevations are in units of feet referenced to the 1988 North American Vertical Datum (NAVD88).
3. United States Environmental Protection Agency (USEPA) overburden borings were advanced using rotasonic drilling technology and hollow stem augers. Soil and rock were logged continuously from 10-foot cored intervals.
4. USEPA bedrock borings were advanced using rotary air hammer drilling technology. Soil and rock were logged in 5 to 10 foot intervals from cuttings brought to the surface during drilling.
5. Borings within the E.C. Electroplating site (ECE) were installed in 1999 by Chapin Engineering using rotary air hammer drilling technology.
6. ppb = parts per billion
7. Cr, VI = hexavalent chromium.
8. NJGS = New Jersey Geological Survey.
9. The depictions of the former Garfield water production wells are based on information obtained from New Jersey well permits. Detailed logs are not available.
10. Bedrock Well ECE-PR-BR borehole extends deeper than 350ft msl and is truncated on this figure.

Figure 1-7

Geologic Cross-Section B - B'

Feasibility Study Report

Garfield Groundwater Contamination Superfund Site

Garfield, NJ 07026

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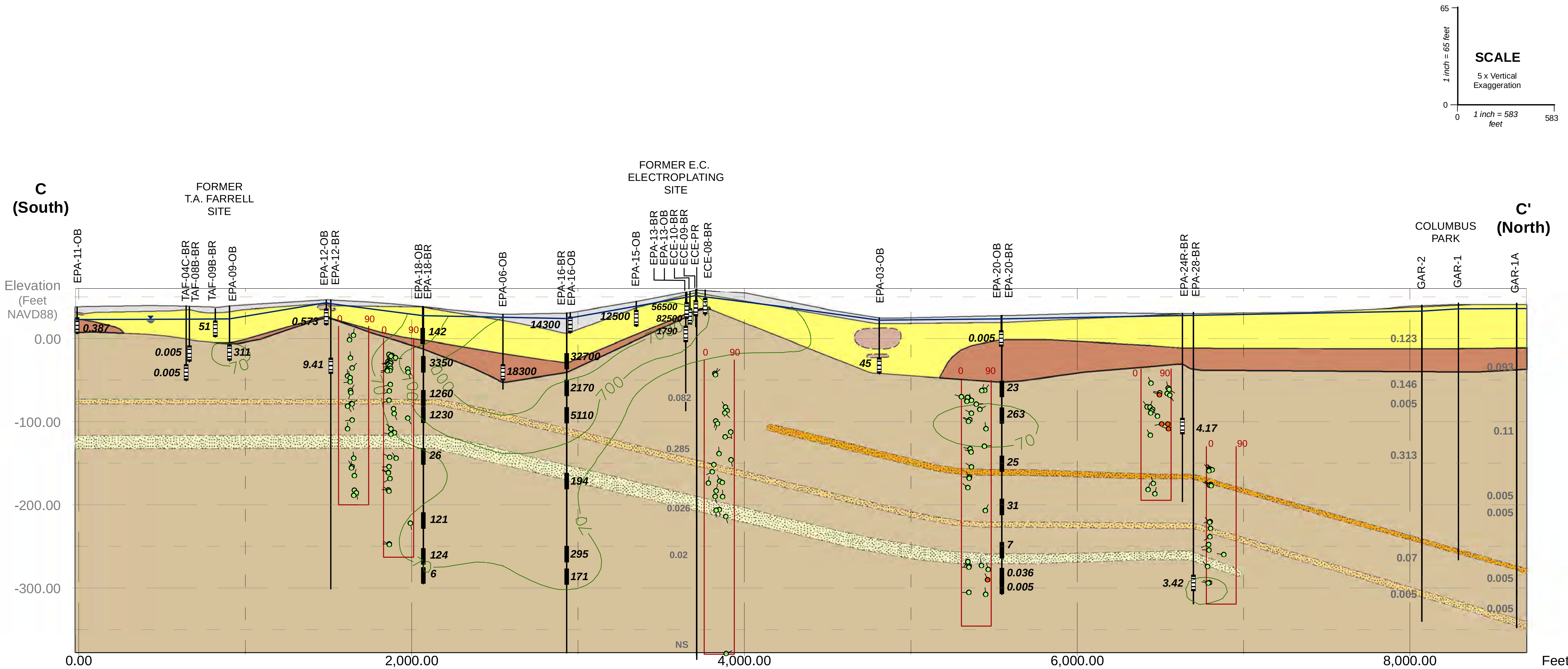

Legend

Potentiometric Groundwater Surface

FLUTe Monitoring Port Interval

Conventional Monitoring Well Screened Interval

Extent of Isolation Casing

-0.02 Unvalitdated Packer Testing Result

5110 Hexavalent Chromium Concentration (ppb) (2012 RI Groundwater Sampling Event #1 and 2013 RI Groundwater Sampling Event)

Depth of Borehole Drilling

Hexavalent Chromium Isoconcentration Contour (ppb)

Inferred Hexavalent Chromium Isoconcentration Contour (ppb)

Sand/Gravel

Silt/Clay

Upper Sandstone

Lower Sandstone

Middle Sandstone

Fill Soils (Inferred in Borings Where Not Logged)

Weathered Bedrock

Interbedded Mudstone Siltstone Sandstone

Applicable Regulatory Criteria:

Analyte	Criteria: New Jersey Department of Environmental Protection - Groundwater Quality Criteria (July 2010)
Cr, VI	*70 ppb

** New Jersey Department of Environmental Protection Groundwater Quality Standards Class IIA Constituent Value for total chromium is being used as a reference for hexavalent chromium.*

Tadpole Plot

0 90

Circle position indicates dip angle. Tail points in azimuth direction: up for north, down for south, right for east, left for west

Fracture/Feature

Hairline Fracture

Notes/Definitions:

1. The potentiometric groundwater surface is based on measurements collected August 7, 2012.
2. Elevations are in units of feet referenced to the 1988 North American Vertical Datum (NAVD88).
3. United States Environmental Protection Agency (USEPA) overburden borings were advanced using rotasonic drilling technology and hollow stem augers. Soil and rock were logged continuously from 10-foot cored intervals.
4. USEPA bedrock borings were advanced using rotary air hammer drilling technology. Soil and rock were logged in 5 to 10 foot intervals from cuttings brought to the surface during drilling.
5. Borings within the E.C. Electroplating site (ECE) were installed in 1999 by Chapin Engineering using rotary air hammer drilling technology.
6. ppb = parts per billion
7. Cr, VI = hexavalent chromium.
8. NJGS = New Jersey Geological Survey.
9. The depictions of the former Garfield water production wells are based on information obtained from New Jersey well permits. Detailed logs are not available.
10. Bedrock wells EPA-16-BR and ECE-PR-BR boreholes extend deeper than 150 ft msl and are truncated on this figure.

Figure 1-8

Geologic Cross-Section C - C'

Feasibility Study Report

Garfield Groundwater Contamination Superfund Site

Garfield, NJ 07026

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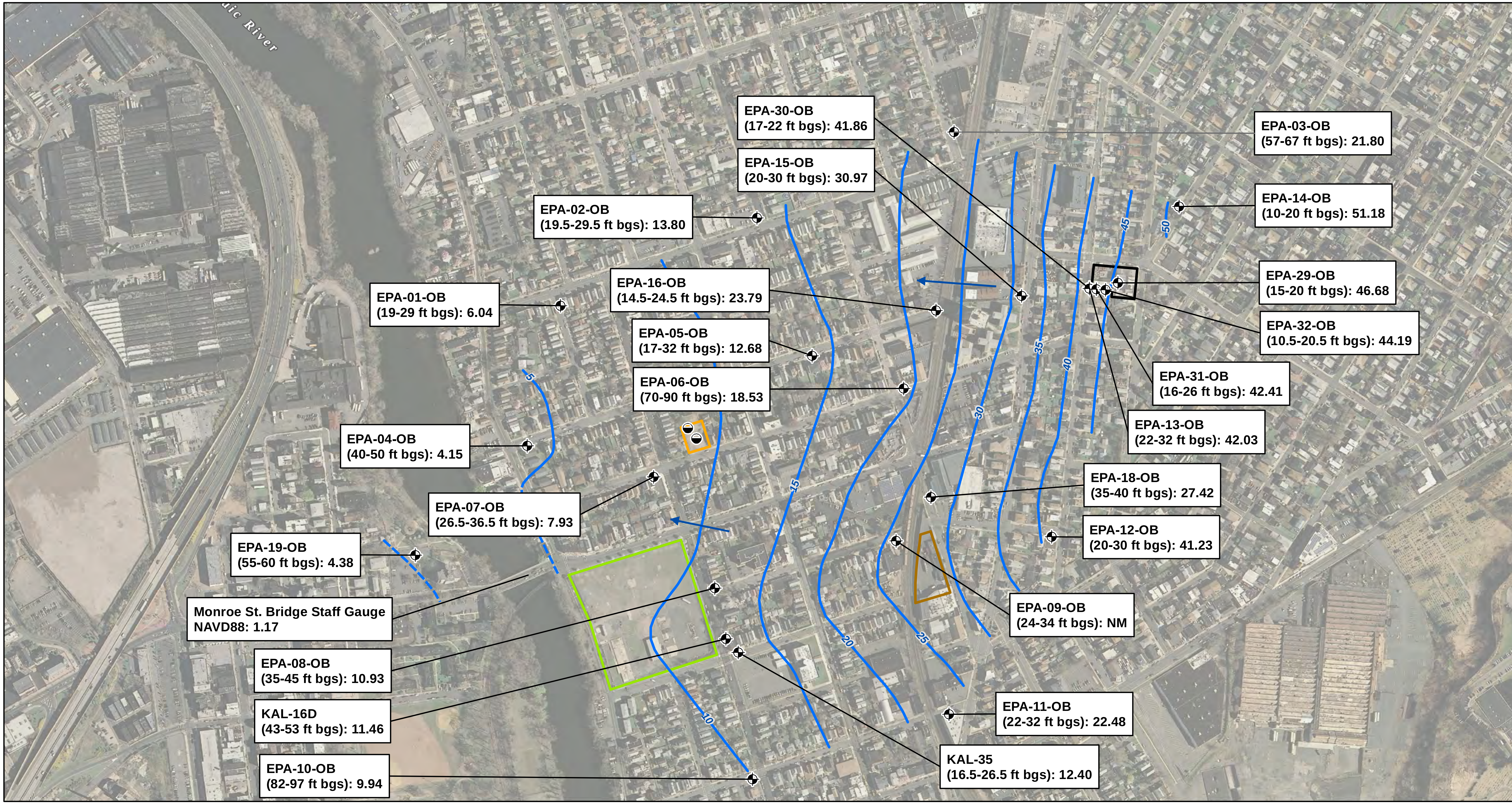

Conventional Monitoring Well
Former Garfield Municipal Well
Grand Street Lot
Kalama Chemical Site
T.A. Farrell Site
E.C. Electoplating Site (125 Clark St., Garfield, NJ)
Overburden Groundwater Contour (ft bgs)
(Dashed Where Inferred)
Inferred Groundwater Flow Direction
EPA-08-OB — Monitoring Well ID
(35-45 ft bgs): 10.93 — Groundwater Elevation (Feet NAVD88)
Screen Interval (Feet Below Ground Surface)

N

NOTES:
New Jersey State Plane Coordinate System
Horizontal Datum NAD83, Vertical Datum NAVD88
US Survey Feet
MSL - Mean Sea Level
NM - Not Measured
Imagery Source: National Aerial Imagery Program, 2010
Isoconcentration lines based on the results of the
2014 Groundwater Sampling Event.
Overburden elevation ranges from 0 to -72.1 ft NAVD88

0 250 500 750 1,000 Feet

Figure 1-9
Garfield December 2014 Overburden Groundwater Contours
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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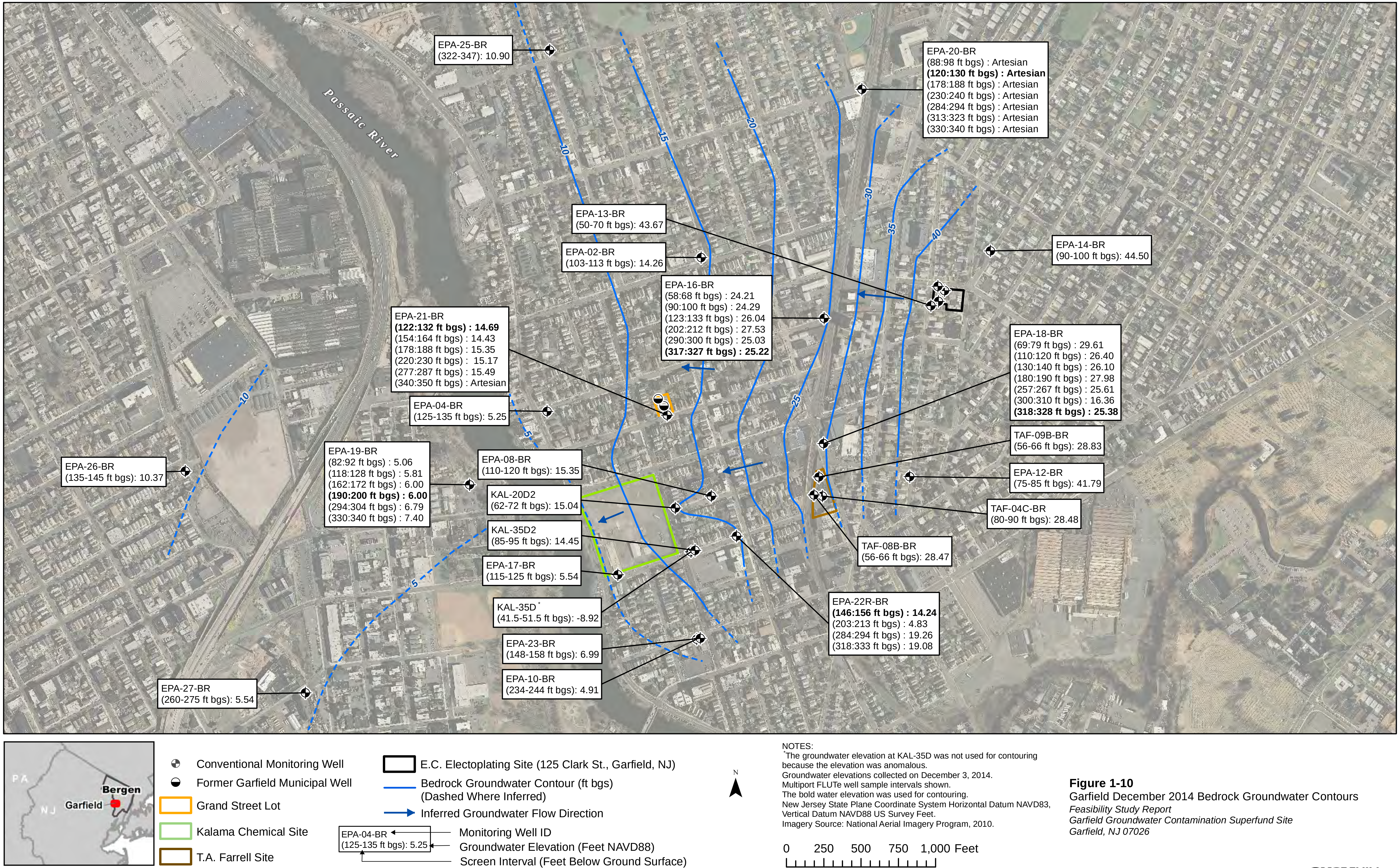

NOTES:
*The groundwater elevation at KAL-35D was not used for contouring because the elevation was anomalous.
Groundwater elevations collected on December 3, 2014.
Multiport FLUTe well sample intervals shown.
The bold water elevation was used for contouring.
New Jersey State Plane Coordinate System Horizontal Datum NAVD83, Vertical Datum NAVD88 US Survey Feet.
Imagery Source: National Aerial Imagery Program, 2010.

Figure 1-10
Garfield December 2014 Bedrock Groundwater Contours
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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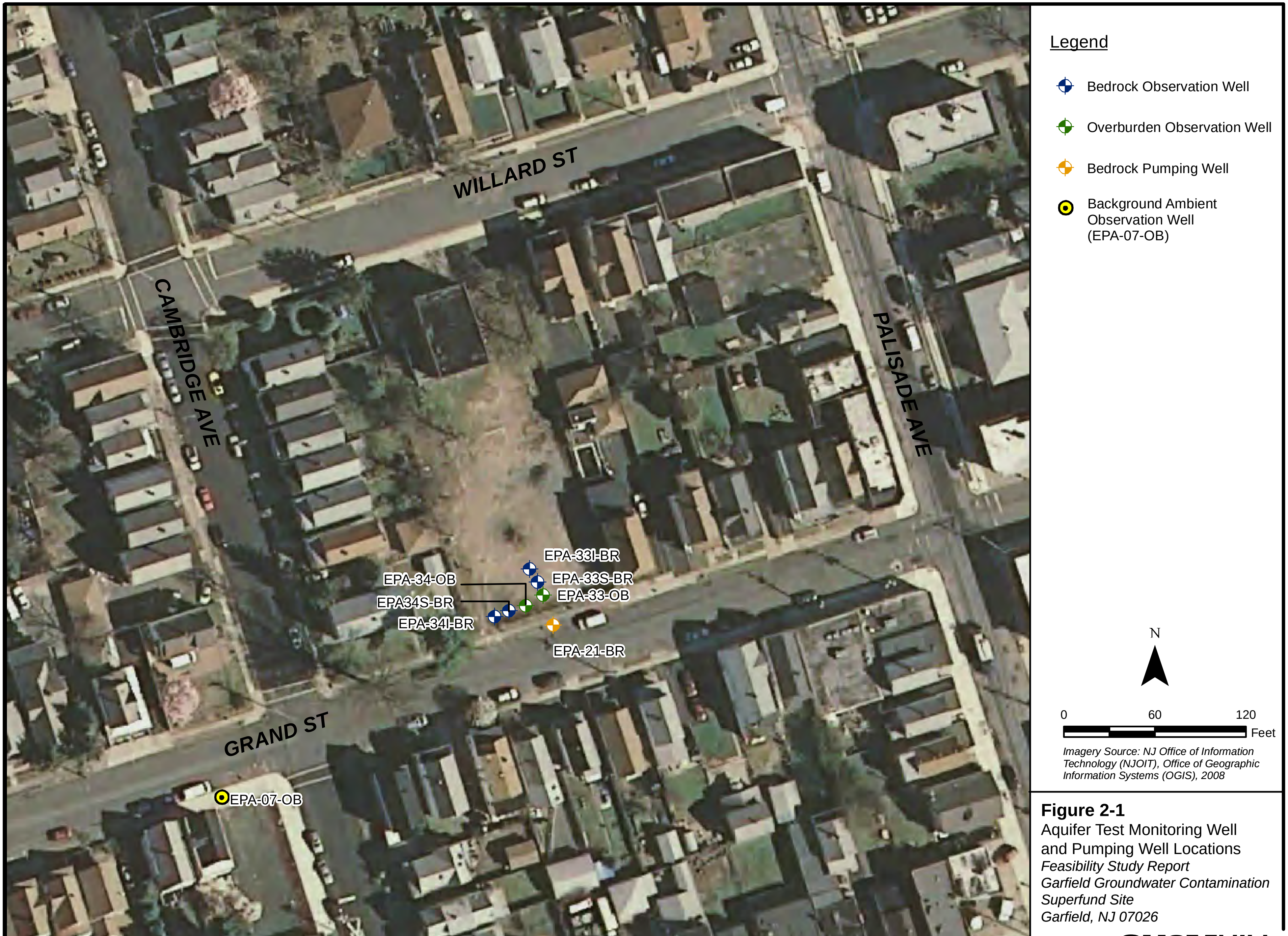

Figure 2-1
Aquifer Test Monitoring Well and Pumping Well Locations
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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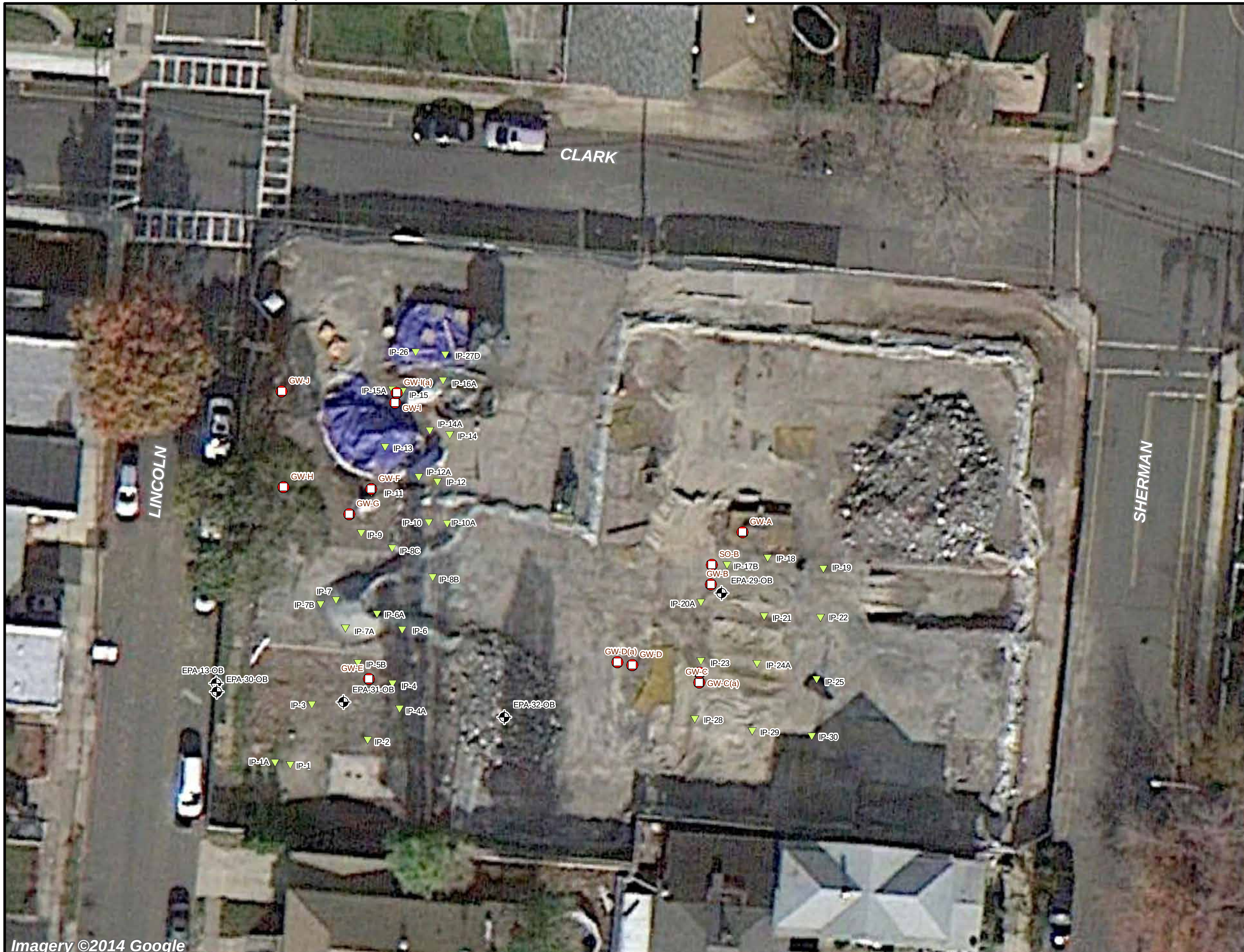

Legend

- Monitoring Well Location
- Injection Point
- Groundwater Grab Location

N

0 12.5 25 50 Feet

NOTES:
New Jersey State Plane Coordinate System, Horizontal Datum NAD83, US Survey Feet
Imagery Source: Google Earth, 2014.

Figure 2-2

Pilot Study Site Map
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site, Garfield, NJ 07026

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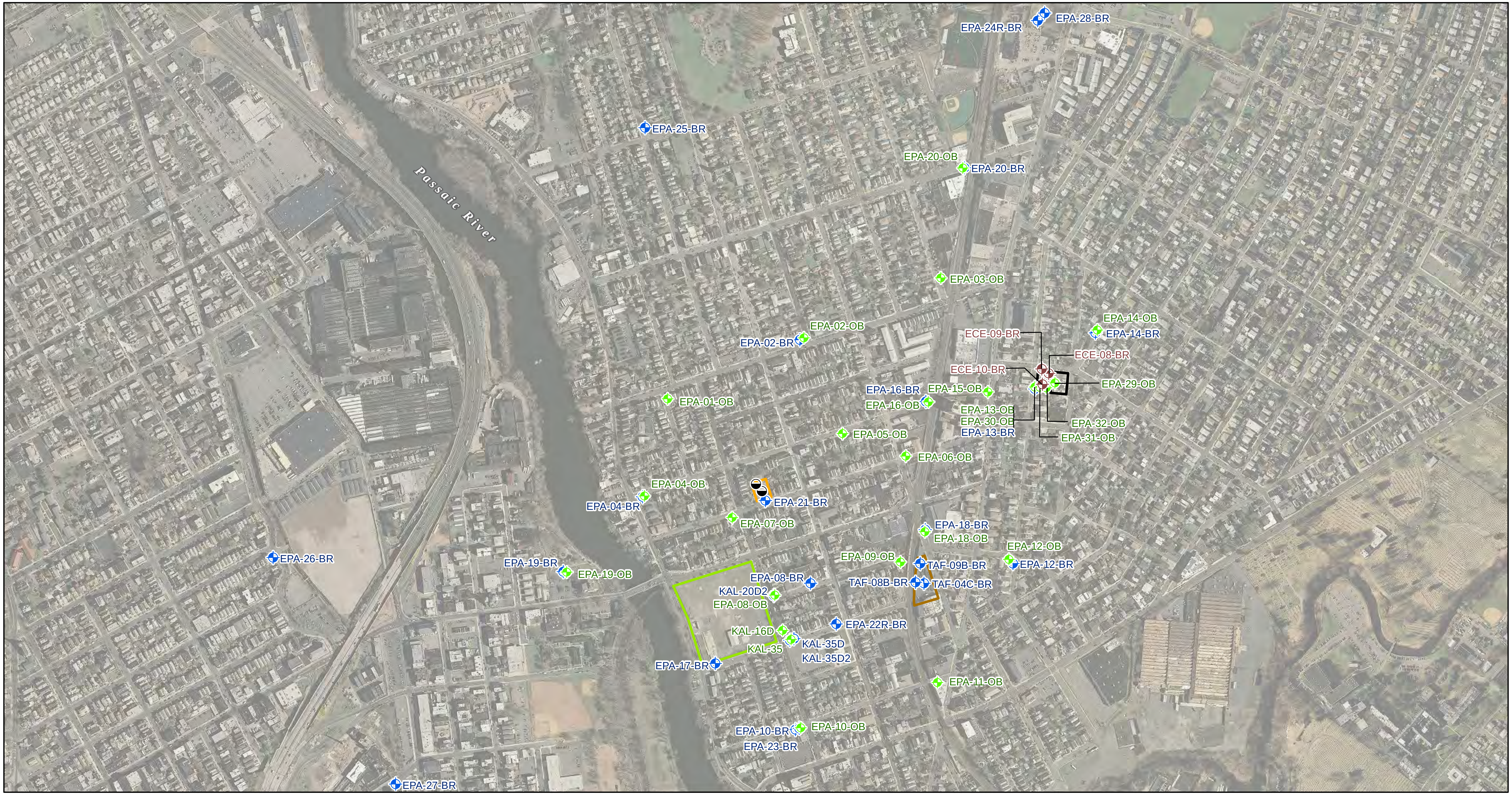

Overburden Monitoring Well
Bedrock Montoring Well
Abandoned Monitoring Well
Former Garfield Municipal Well
Grand Street Lot
Kalama Chemical Site
T.A. Farrell Site
E.C. Electoplating Site
(125 Clark St., Garfield, NJ)

NOTES:
New Jersey State Plane Coordinate
System Horizontal Datum NAVD83,
Imagery Source: National Aerial
Imagery Program, 2010.

0 250 500 750 1,000 Feet

N

Figure 2-3
Groundwater Monitoring Network
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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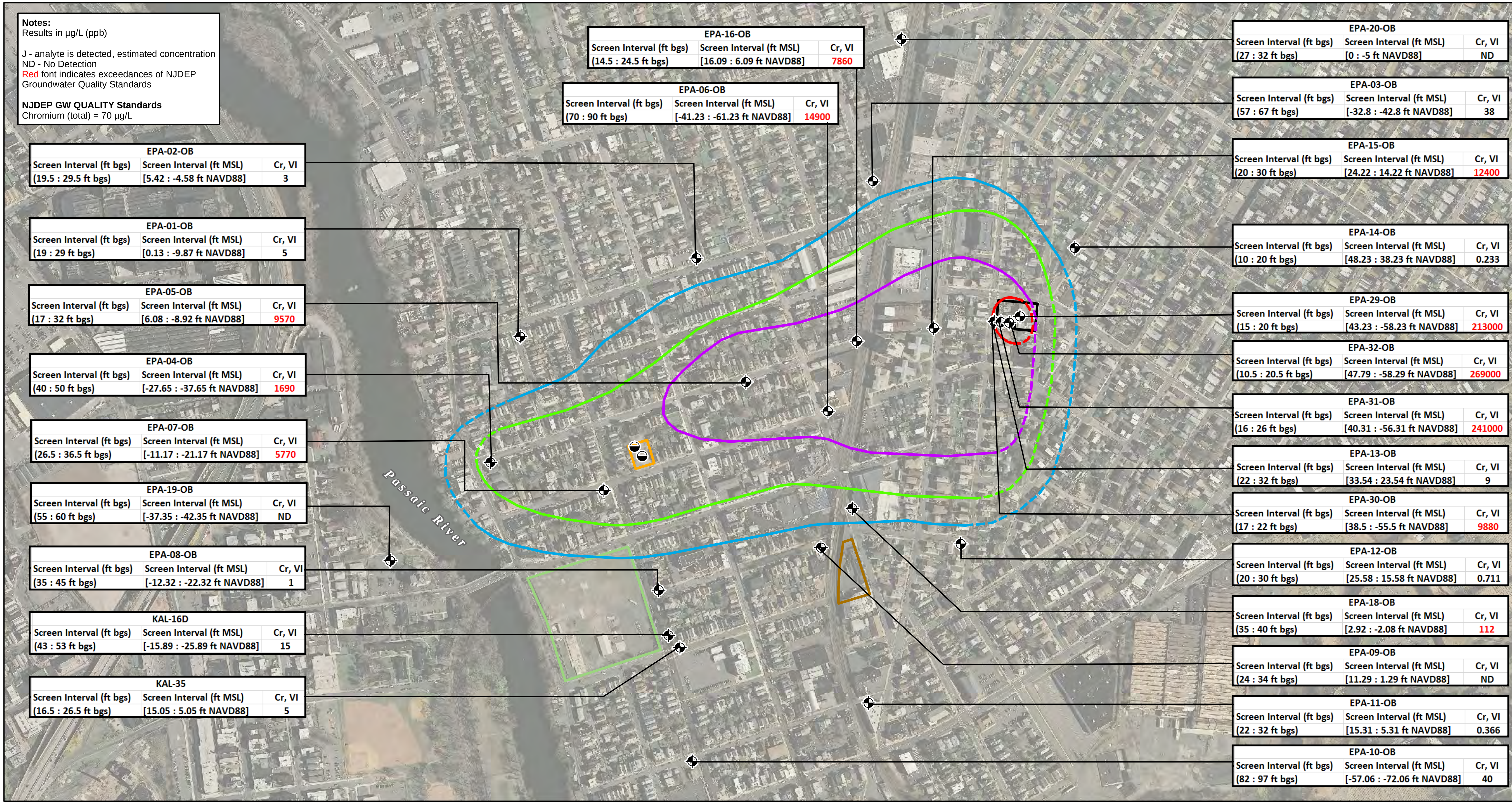

Conventional Monitoring Well
Former Garfield Municipal Well
Grand Street Lot
Kalama Chemical Site
T.A. Farrell Site
E.C. Electoplating Site (125 Clark St., Garfield, NJ)

Approximate Hexavalent Chromium Isoconcentration Contour Lines
70 µg/L (dashed where inferred)
700 µg/L (dashed where inferred)
7000 µg/L (dashed where inferred)
70,000 µg/L (dashed where inferred)

0 250 500 750 1,000 Feet

N

NOTES:
New Jersey State Plane Coordinate System Horizontal Datum NAD83, Vertical Datum NAVD88 US Survey Feet.
MSL - Mean Sea Level
ND - Not Detected
Imagery Source: National Aerial Imagery Program, 2010
The hexavalent chromium analytical result from EPA-13-OB was not honored by the isoconcentration contour lines because it was anomalously low due to the effectiveness of the 2014 Pilot Study.
Screen Interval 1 (Feet Below Ground Surface)
Screen Interval 2 (Feet NAVD88)
Overburden elevation ranges from 0 to -72.1 ft NAVD88

Figure 2-4
Garfield December 2014 Overburden Hexavalent Chromium Isoconcentration Contours
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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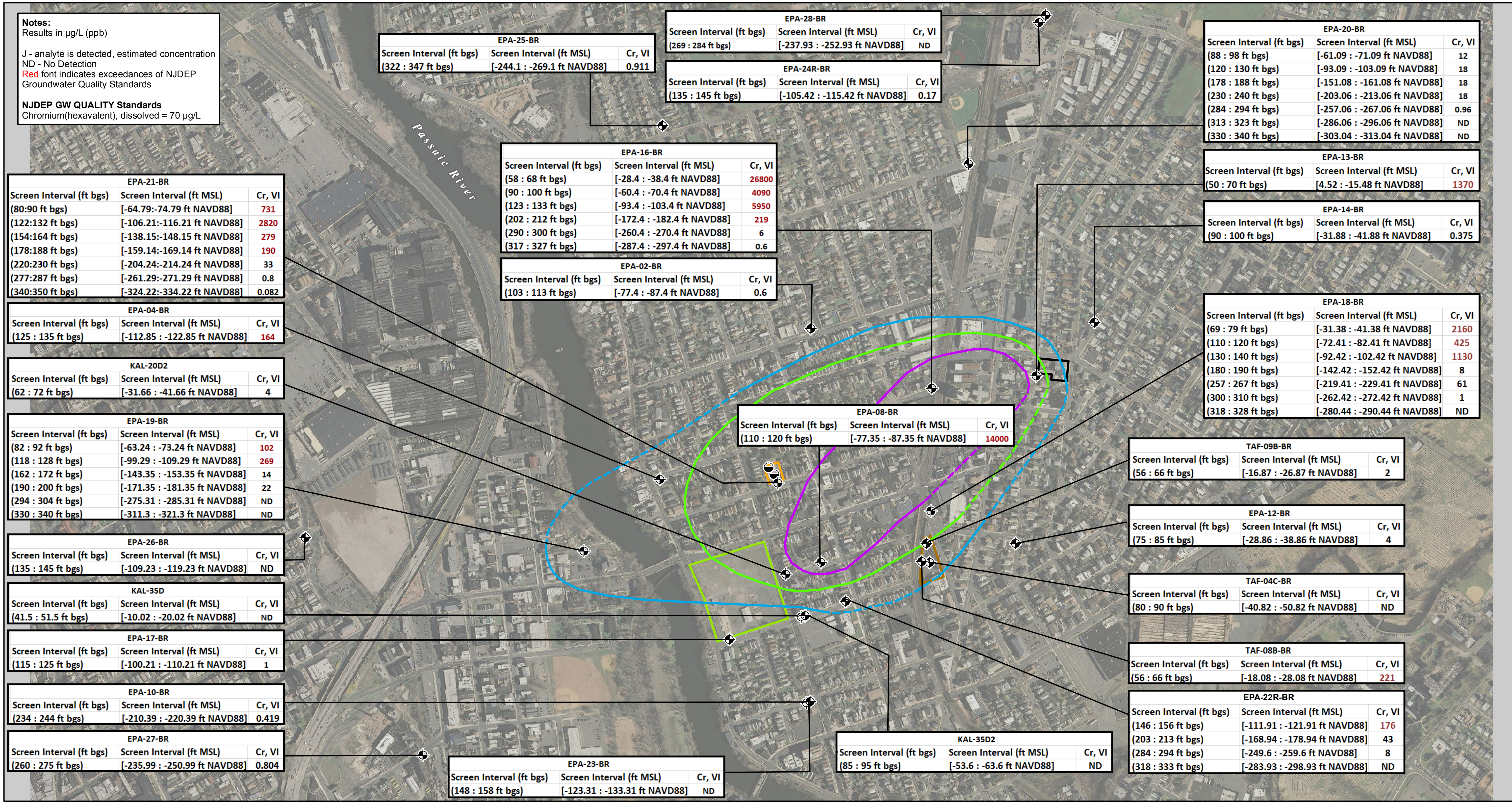
CH2MHILL.



Notes:
Results in µg/L (ppb)

J - analyte is detected, estimated concentration
ND - No Detection
Red font indicates exceedances of NJDEP Groundwater Quality Standards

NJDEP GW QUALITY Standards
Chromium(hexavalent), dissolved = 70 µg/L

EPA-21-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(80:90 ft bgs)	[-64.79:-74.79 ft NAVD88]	731
(122:132 ft bgs)	[-106.21:-116.21 ft NAVD88]	2820
(154:164 ft bgs)	[-138.15:-148.15 ft NAVD88]	279
(178:188 ft bgs)	[-159.14:-169.14 ft NAVD88]	190
(220:230 ft bgs)	[-204.24:-214.24 ft NAVD88]	33
(277:287 ft bgs)	[-261.29:-271.29 ft NAVD88]	0.8
(340:350 ft bgs)	[-324.22:-334.22 ft NAVD88]	0.082

EPA-04-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(125 : 135 ft bgs)	[-112.85 : -122.85 ft NAVD88]	164

KAL-20D2

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(62 : 72 ft bgs)	[-31.66 : -41.66 ft NAVD88]	4

EPA-19-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(82 : 92 ft bgs)	[-63.24 : -73.24 ft NAVD88]	102
(118 : 128 ft bgs)	[-99.29 : -109.29 ft NAVD88]	269
(162 : 172 ft bgs)	[-143.35 : -153.35 ft NAVD88]	14
(190 : 200 ft bgs)	[-171.35 : -181.35 ft NAVD88]	22
(294 : 304 ft bgs)	[-275.31 : -285.31 ft NAVD88]	ND
(330 : 340 ft bgs)	[-311.3 : -321.3 ft NAVD88]	ND

EPA-26-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(135 : 145 ft bgs)	[-109.23 : -119.23 ft NAVD88]	ND

KAL-35D

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(41.5 : 51.5 ft bgs)	[-10.02 : -20.02 ft NAVD88]	ND

EPA-17-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(115 : 125 ft bgs)	[-100.21 : -110.21 ft NAVD88]	1

EPA-10-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(234 : 244 ft bgs)	[-210.39 : -220.39 ft NAVD88]	0.419

EPA-27-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(260 : 275 ft bgs)	[-235.99 : -250.99 ft NAVD88]	0.804

EPA-25-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(322 : 347 ft bgs)	[-244.1 : -269.1 ft NAVD88]	0.911

EPA-28-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(269 : 284 ft bgs)	[-237.93 : -252.93 ft NAVD88]	ND

EPA-24R-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(135 : 145 ft bgs)	[-105.42 : -115.42 ft NAVD88]	0.17

EPA-16-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(58 : 68 ft bgs)	[-28.4 : -38.4 ft NAVD88]	26800
(90 : 100 ft bgs)	[-60.4 : -70.4 ft NAVD88]	4090
(123 : 133 ft bgs)	[-93.4 : -103.4 ft NAVD88]	5950
(202 : 212 ft bgs)	[-172.4 : -182.4 ft NAVD88]	219
(290 : 300 ft bgs)	[-260.4 : -270.4 ft NAVD88]	6
(317 : 327 ft bgs)	[-287.4 : -297.4 ft NAVD88]	0.6

EPA-02-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(103 : 113 ft bgs)	[-77.4 : -87.4 ft NAVD88]	0.6

EPA-08-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(110 : 120 ft bgs)	[-77.35 : -87.35 ft NAVD88]	14000

EPA-23-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(148 : 158 ft bgs)	[-123.31 : -133.31 ft NAVD88]	ND

KAL-35D2

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(85 : 95 ft bgs)	[-53.6 : -63.6 ft NAVD88]	ND

EPA-20-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(88 : 98 ft bgs)	[-61.09 : -71.09 ft NAVD88]	12
(120 : 130 ft bgs)	[-93.09 : -103.09 ft NAVD88]	18
(178 : 188 ft bgs)	[-151.08 : -161.08 ft NAVD88]	18
(230 : 240 ft bgs)	[-203.06 : -213.06 ft NAVD88]	18
(284 : 294 ft bgs)	[-257.06 : -267.06 ft NAVD88]	0.96
(313 : 323 ft bgs)	[-286.06 : -296.06 ft NAVD88]	ND
(330 : 340 ft bgs)	[-303.04 : -313.04 ft NAVD88]	ND

EPA-13-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(50 : 70 ft bgs)	[4.52 : -15.48 ft NAVD88]	1370

EPA-14-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(90 : 100 ft bgs)	[-31.88 : -41.88 ft NAVD88]	0.375

EPA-18-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(69 : 79 ft bgs)	[-31.38 : -41.38 ft NAVD88]	2160
(110 : 120 ft bgs)	[-72.41 : -82.41 ft NAVD88]	425
(130 : 140 ft bgs)	[-92.42 : -102.42 ft NAVD88]	1130
(180 : 190 ft bgs)	[-142.42 : -152.42 ft NAVD88]	8
(257 : 267 ft bgs)	[-219.41 : -229.41 ft NAVD88]	61
(300 : 310 ft bgs)	[-262.42 : -272.42 ft NAVD88]	1
(318 : 328 ft bgs)	[-280.44 : -290.44 ft NAVD88]	ND

TAF-09B-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(56 : 66 ft bgs)	[-16.87 : -26.87 ft NAVD88]	2

EPA-12-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(75 : 85 ft bgs)	[-28.86 : -38.86 ft NAVD88]	4

TAF-04C-BR

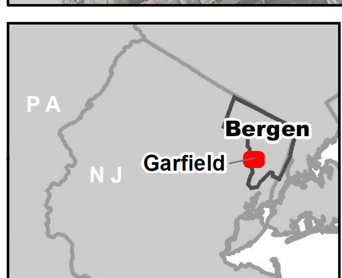
Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(80 : 90 ft bgs)	[-40.82 : -50.82 ft NAVD88]	ND

TAF-08B-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(56 : 66 ft bgs)	[-18.08 : -28.08 ft NAVD88]	221

EPA-22R-BR

Screen Interval (ft bgs)	Screen Interval (ft MSL)	Cr, VI
(146 : 156 ft bgs)	[-111.91 : -121.91 ft NAVD88]	176
(203 : 213 ft bgs)	[-168.94 : -178.94 ft NAVD88]	43
(284 : 294 ft bgs)	[-249.6 : -259.6 ft NAVD88]	8
(318 : 333 ft bgs)	[-283.93 : -298.93 ft NAVD88]	ND



Conventional Monitoring Well
Former Garfield Municipal Well
Grand Street Lot
Kalama Chemical Site
T.A. Farrell Site
E.C. Electoplating Site (125 Clark St., Garfield, NJ)

Approximate Hexavalent Chromium Isoconcentration Contour Lines

70 µg/L (dashed where inferred)
700 µg/L (dashed where inferred)
7000 µg/L (dashed where inferred)

NOTE: Bedrock groundwater sample elevations range from -10.02 to -334.22 feet NAVD88, and the contours show the greatest Cr(VI) concentrations throughout the bedrock water column.

N

NOTES:
New Jersey State Plane Coordinate System
Horizontal Datum NAD83, Vertical Datum NAVD88
US Survey Feet
MSL - Mean Sea Level
ND - Not Detected
Imagery Source: National Aerial Imagery Program
Imagery Date: 2010

0 250 500 750 1,000 Feet

Figure 2-5
Garfield December 2014 Bedrock Hexavalent Chromium Isoconcentration Contours
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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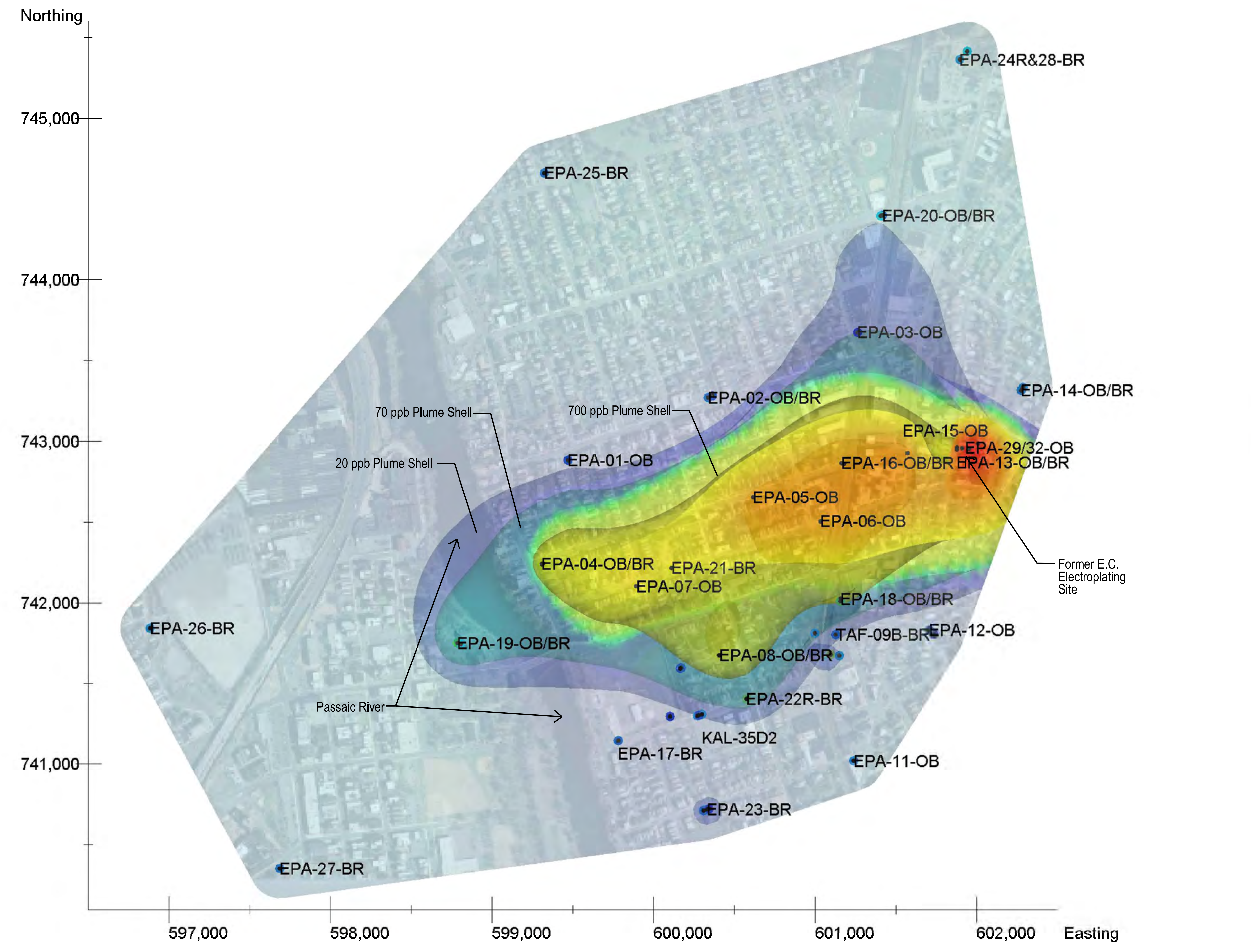


NOTES:

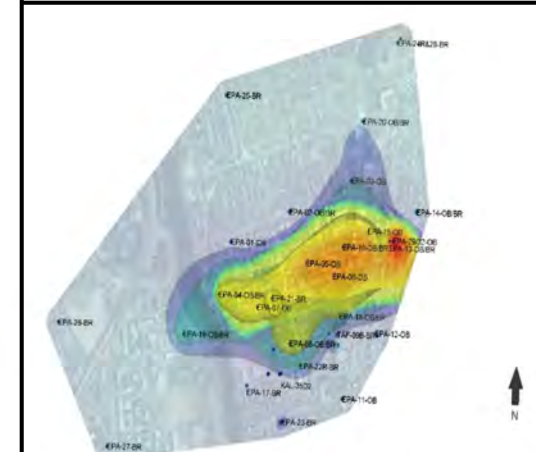
1) New Jersey State Plane Coordinate System Horizontal Datum NAD83, Vertical Datum NAVD88 US Survey Feet

2) Imagery Source: National Aerial Imagery Program Imagery Date: 2010

3) Aerial image overlain on water table surface, vadose zone not depicted

4) The saturated zone depiction is based on groundwater elevation data collected during the December 2014 synoptic water level measurement round. The groundwater elevation data used to depict the saturated zone at each FLUTe well was obtained from averaging the groundwater elevation of each FLUTe port.

5) The color break between green and blue shading occurs at 70 µg/L.



Basemap - Oriented Parallel to Plume View

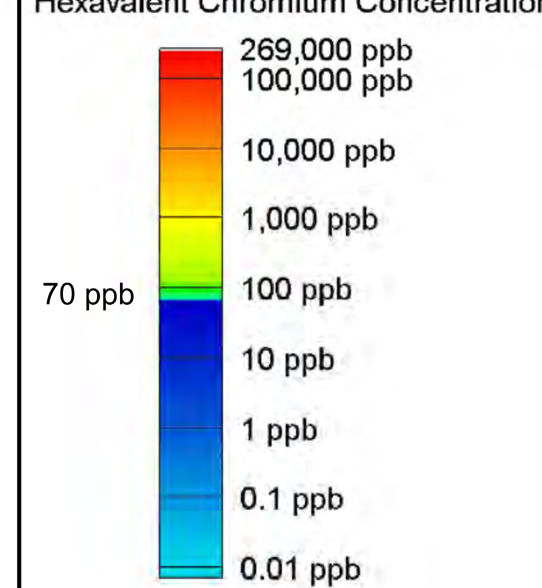
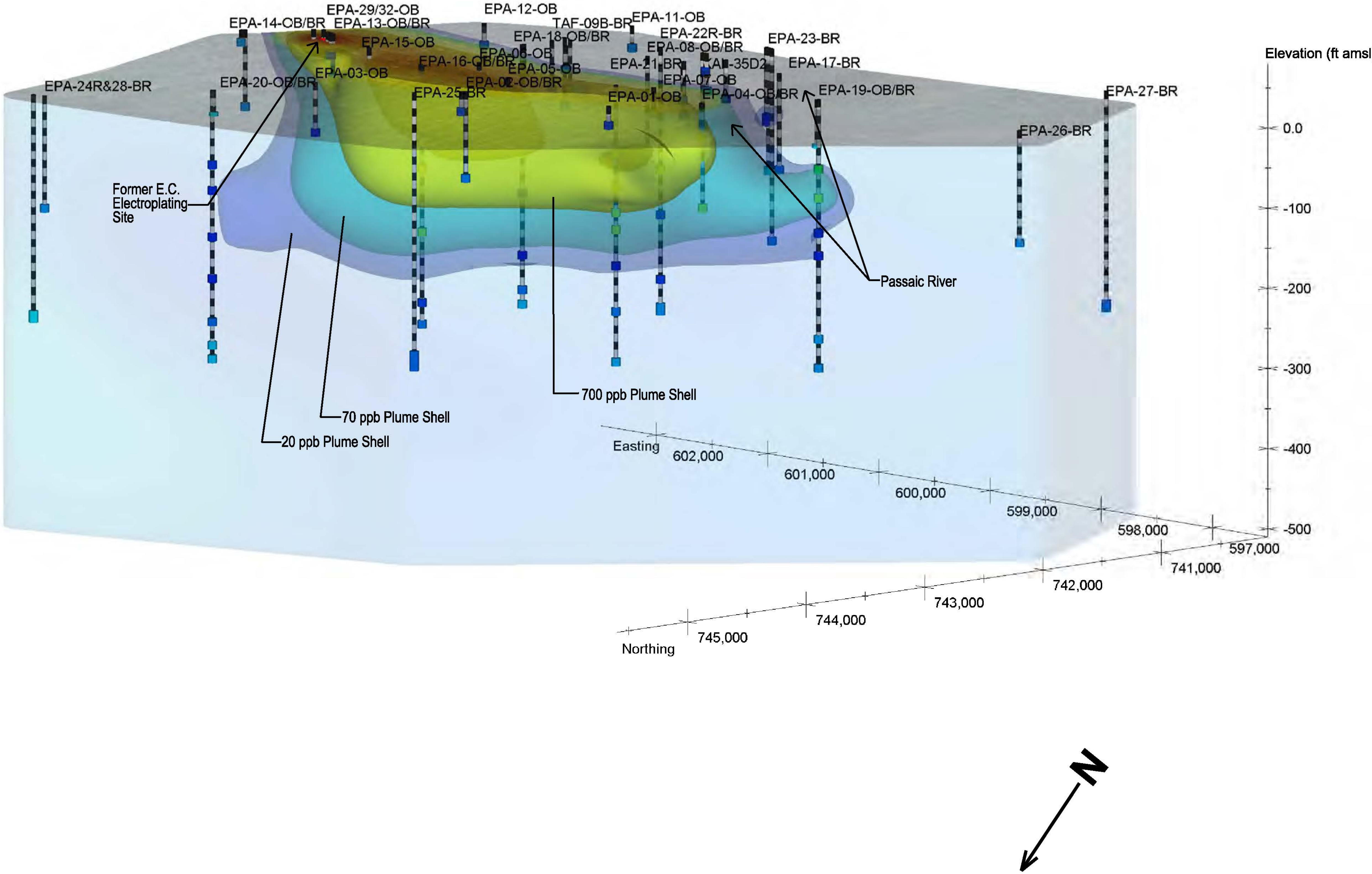


Figure 2-6
View of Hexavalent Chromium Plume in Groundwater – Aerial View
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

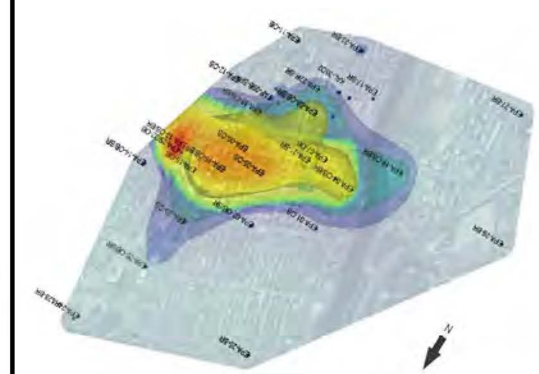
CH2MHILL

PROJECTWISE | F80_431007.DGN



NOTES:

1) New Jersey State Plane Coordinate System Horizontal Datum NAD83, Vertical Datum NAVD88 US Survey Feet
2) Imagery Source: National Aerial Imagery Program Imagery Date: 2010
3) Aerial image overlain on water table surface, vadose zone not depicted
4) The saturated zone depiction is based on groundwater elevation data collected during the December 2014 synoptic water level measurement round. The groundwater elevation data used to depict the saturated zone at each FLUTe well was obtained from averaging the groundwater elevation of each FLUTe port.
5) The color break between green and blue shading occurs at 70 µg/L.



Basemap - Oriented Parallel to Plume View

Hexavalent Chromium Concentration

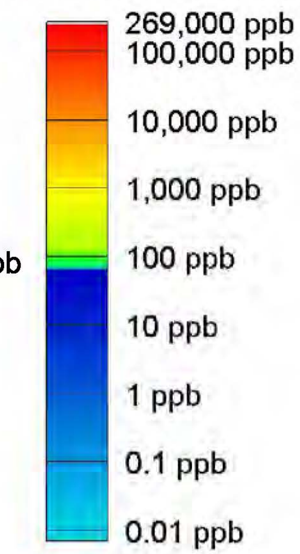
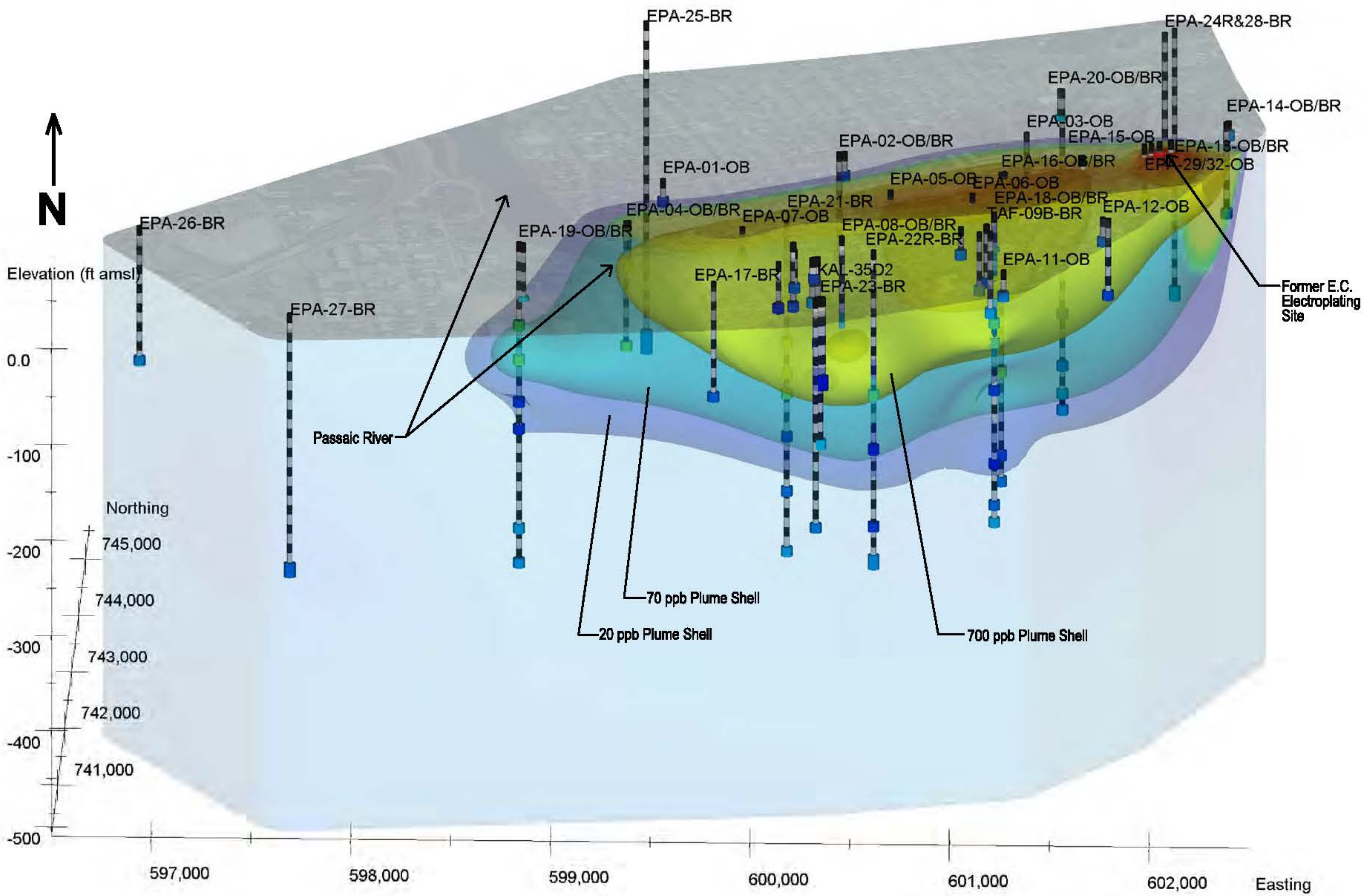


Figure 2-7
3D View of Hexavalent Chromium Plume in Groundwater – Northwest to Southeast, View Looking Down Slightly from Above Horizontal Plane
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

PROJECTWISE | F82_431007.DGN

CH2MHILL



NOTES:

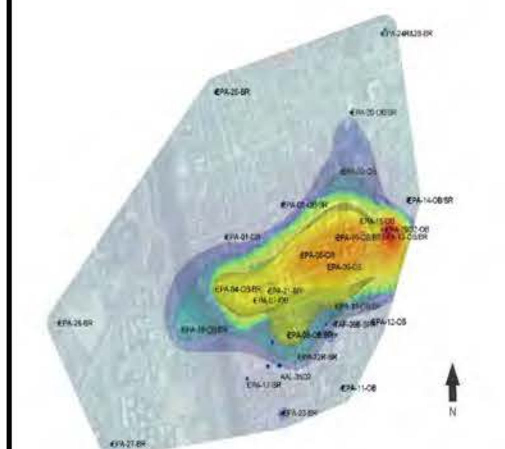
1) New Jersey State Plane Coordinate System Horizontal Datum NAD83, Vertical Datum NAVD88 US Survey Feet

2) Imagery Source: National Aerial Imagery Program Imagery Date: 2010

3) Aerial image overlain on water table surface, vadose zone not depicted

4) The saturated zone depiction is based on groundwater elevation data collected during the December 2014 synoptic water level measurement round. The groundwater elevation data used to depict the saturated zone at each FLUTe well was obtained from averaging the groundwater elevation of each FLUTe port.

5) The color break between green and blue shading occurs at 70 µg/L.



Basemap - Oriented Parallel to Plume View

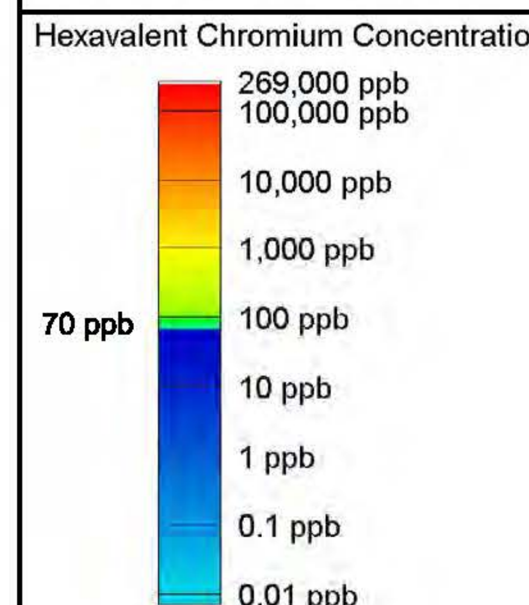


Figure 2-8
3D View of Hexavalent Chromium Plume in Groundwater – South to North, View Looking Down Slightly from Above Horizontal Plane

Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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Figure 3-1

Summary of Residential and Commercial Basements Sampled

Feasibility Study Report
Garfield Groundwater Contamination Superfund Site, Garfield, NJ 07026

CH2MHILL.

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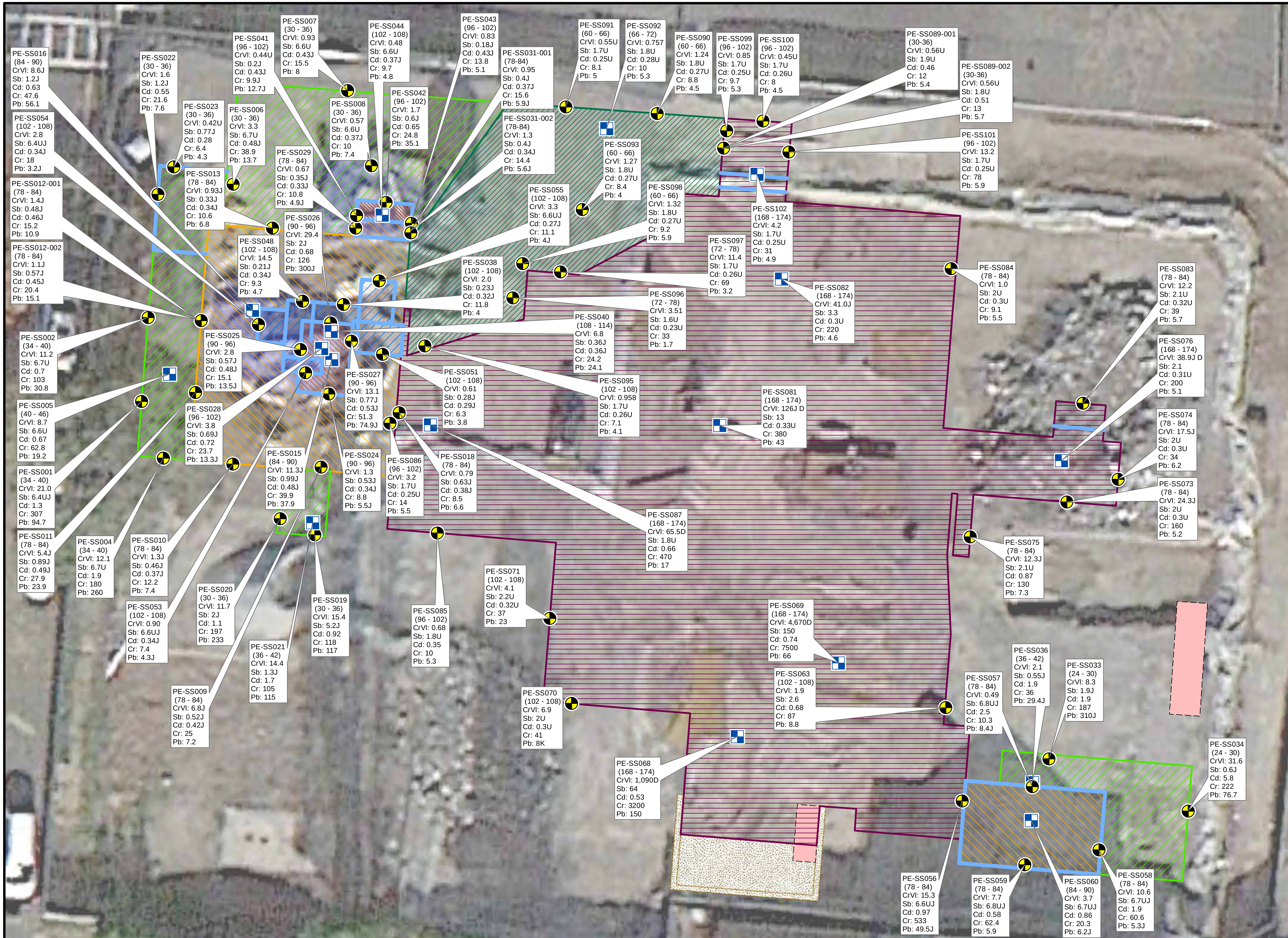
Notes:
Results presented in milligrams per kilogram (mg/kg)
Depth measured in inches
Locations with two sets of samples include a duplicate sample indicated with "-002" in the Sample ID

NJDEP Soil Remediation Standards:
Hexavalent Chromium = 20 mg/kg
Antimony = 31 mg/kg
Cadmium = 78 mg/kg
Lead = 400 mg/kg
Total Chromium - No Standard

Data Validator Qualifiers:
U: Not Detected
J: Estimated Value
J-: The result is an estimated quantity, but the result may be biased low.
D: Diluted

Figure 3-2
Excavation Samples
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

CH2MHILL.



Legend

Post-excavation Sample
- Base
- Sidewall
- Over-excavations
- UndergroundStorageTanks
- FillandWallLocations

Excavation Depth
- 3 Feet
- 5 Feet
- 7 Feet
- 8 Feet
- 8.5 Feet
- 9 Feet
- 14 Feet

Notes:
Results presented in milligrams per kilogram (mg/kg). Depth measured in inches. Locations with two sets of samples include a duplicate sample indicated with "-002" in the Sample ID

NJDEP Soil Remediation Standards:
Hexavalent Chromium = 20 mg/kg
Antimony = 31 mg/kg
Cadmium = 78 mg/kg
Lead = 400 mg/kg
Total Chromium - No Standard

Data Validator Qualifiers:
U: Not Detected
J: Estimated Value
J-: The result is an estimated quantity, but the result may be biased low.
D: Diluted

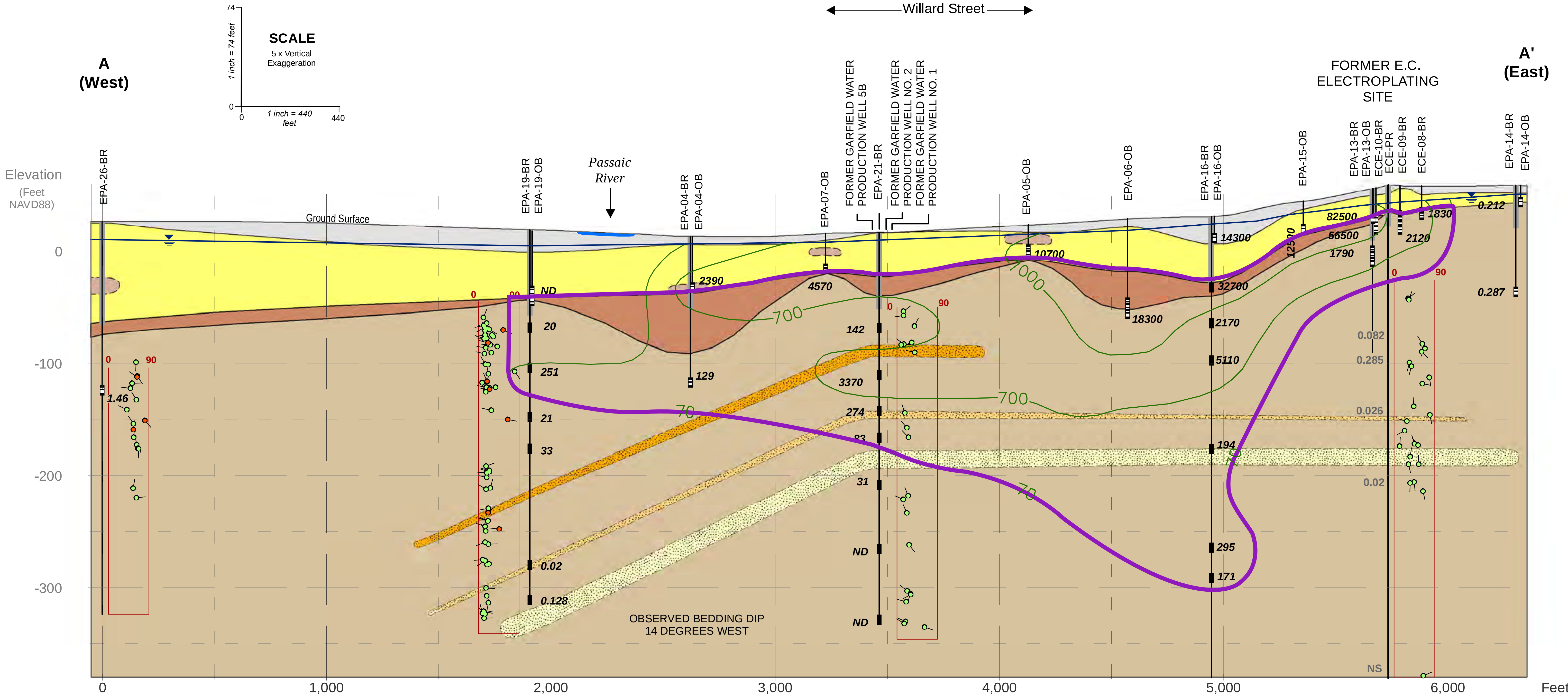
N W E S

0 5 10 20 Feet

Figure 3-3
Final Post Excavation Samples

Feasibility Study Report
Garfield Groundwater Contamination Superfund Site, Garfield, NJ 07026

CH2MHILL.



Legend

- Potentiometric Groundwater Surface
- FLUTe Monitoring Port Interval
- Conventional Monitoring Well Screened Interval
- Extent of Isolation Casing
- -0.02 Unvalitdated Packer Testing Result
- 5110 Hexavalent Chromium Concentration (ppb) (2012 RI Groundwater Sampling Event #1 and 2013 RI Groundwater Sampling Event)
- Depth of Borehole Drilling
- Hexavalent Chromium Isoconcentration Contour (ppb)
- Inferred Hexavalent Chromium Isoconcentration Contour (ppb)
- Sand/Gravel
- Silt/Clay
- Upper Sandstone
- Lower Sandstone
- Middle Sandstone
- Fill Soils (Inferred in Borings Where Not Logged)
- Weathered Bedrock
- Interbedded Mudstone Siltstone Sandstone
- TI Zone

Tadpole Plot

0 90

Circle position indicates dip angle. Tail points in azimuth direction: up for north, down for south, right for east, left for west

- Fracture/Feature
- Hairline Fracture

Applicable Regulatory Criteria:

Analyte	Criteria New Jersey Department of Environmental Protection - Groundwater Quality Criteria (July 2010)
Cr, VI	*70 ppb

** New Jersey Department of Environmental Protection Groundwater Quality Standards Class IIA Constituent Value for total chromium is being used as a reference for hexavalent chromium.*

Notes/Definitions:

1. The potentiometric groundwater surface is based on measurements collected August 7, 2012.
2. Elevations are in units of feet referenced to the 1988 North American Vertical Datum (NAVD88).
3. United States Environmental Protection Agency (USEPA) overburden borings were advanced using rotasonic drilling technology and hollow stem augers. Soil and rock were logged continuously from 10-foot cored intervals.
4. USEPA bedrock borings were advanced using rotary air hammer drilling technology. Soil and rock were logged in 5 to 10 foot intervals from cuttings brought to the surface during drilling.
5. Borings within the E.C. Electroplating site (ECE) were installed in 1999 by Chapin Engineering using rotary air hammer drilling technology.
6. ppb = parts per billion
7. Cr, VI = hexavalent chromium.
8. NJGS = New Jersey Geological Survey.
9. The depictions of the former Garfield water production wells are based on information obtained from New Jersey well permits. Detailed logs are not available.
10. Bedrock wells EPA-16-BR and ECE-PR-BR boreholes extend deeper than 350 ft msl and are truncated on this figure.

Figure 6-1

Geologic Cross-Section A-A' with Vertical Extent of TI Zone

Feasibility Study Report

Garfield Groundwater Contamination Superfund Site

Garfield, NJ 07026

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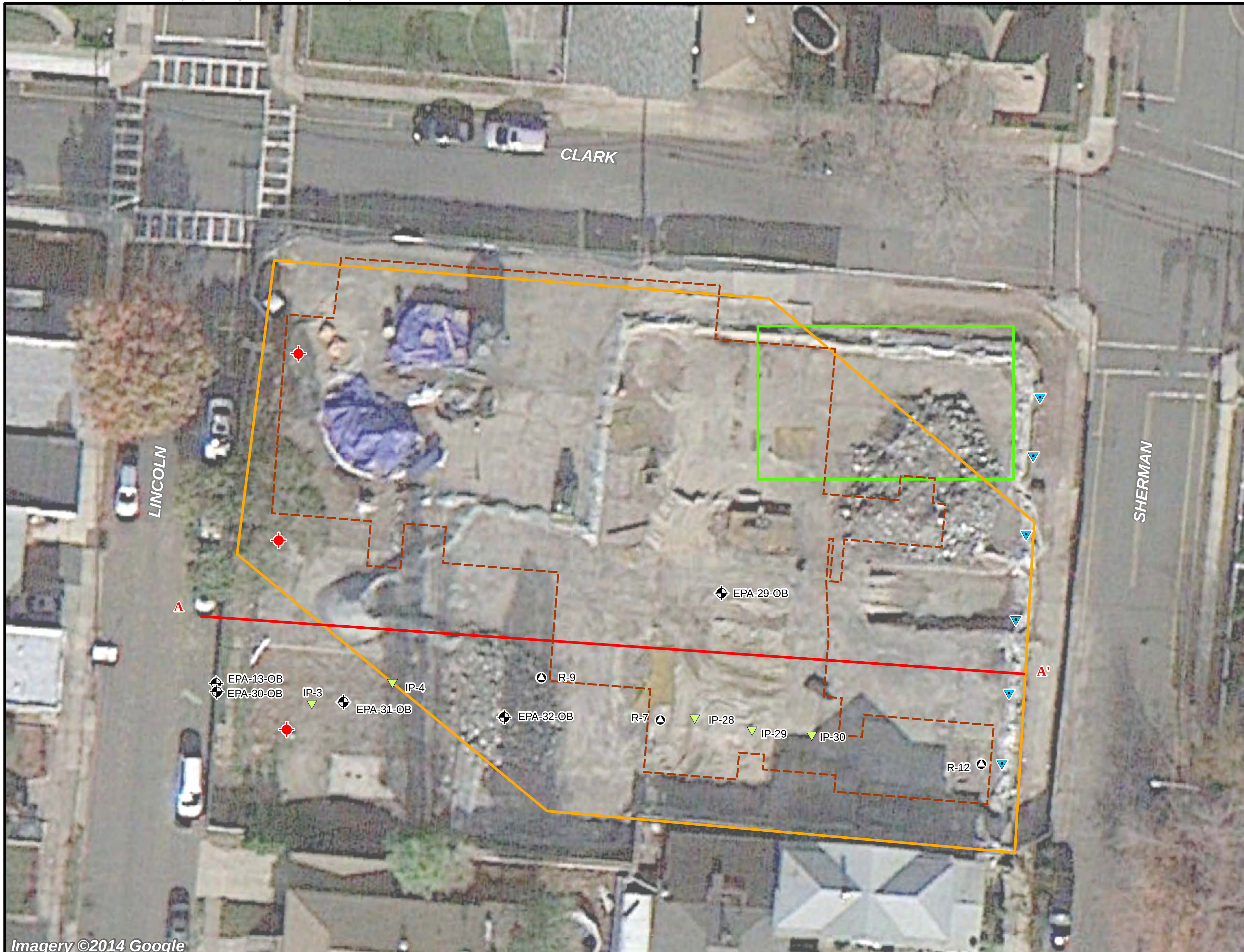

Legend

- Monitoring Well Location
- Soil Boring
- Bedrock Injection Well
- Bedrock Extraction Well
- Pilot Study Direct Push Injection Location
- Groundwater Treatment System Building
- Soil Mixing Area
- 2013-2014 Excavation Area
- Cross-section Transect

N

0 12.5 25 50 Feet

NOTES:

New Jersey State Plane Coordinate System, Horizontal Datum NAD83, US Survey Feet
Imagery Source: Google Earth, 2014.

Figure 7-1

Alternative 2A: Source Treatment - Soil Mixing, Plan View

Feasibility Study Report

Garfield Groundwater Contamination Superfund Site, Garfield NJ, 07026

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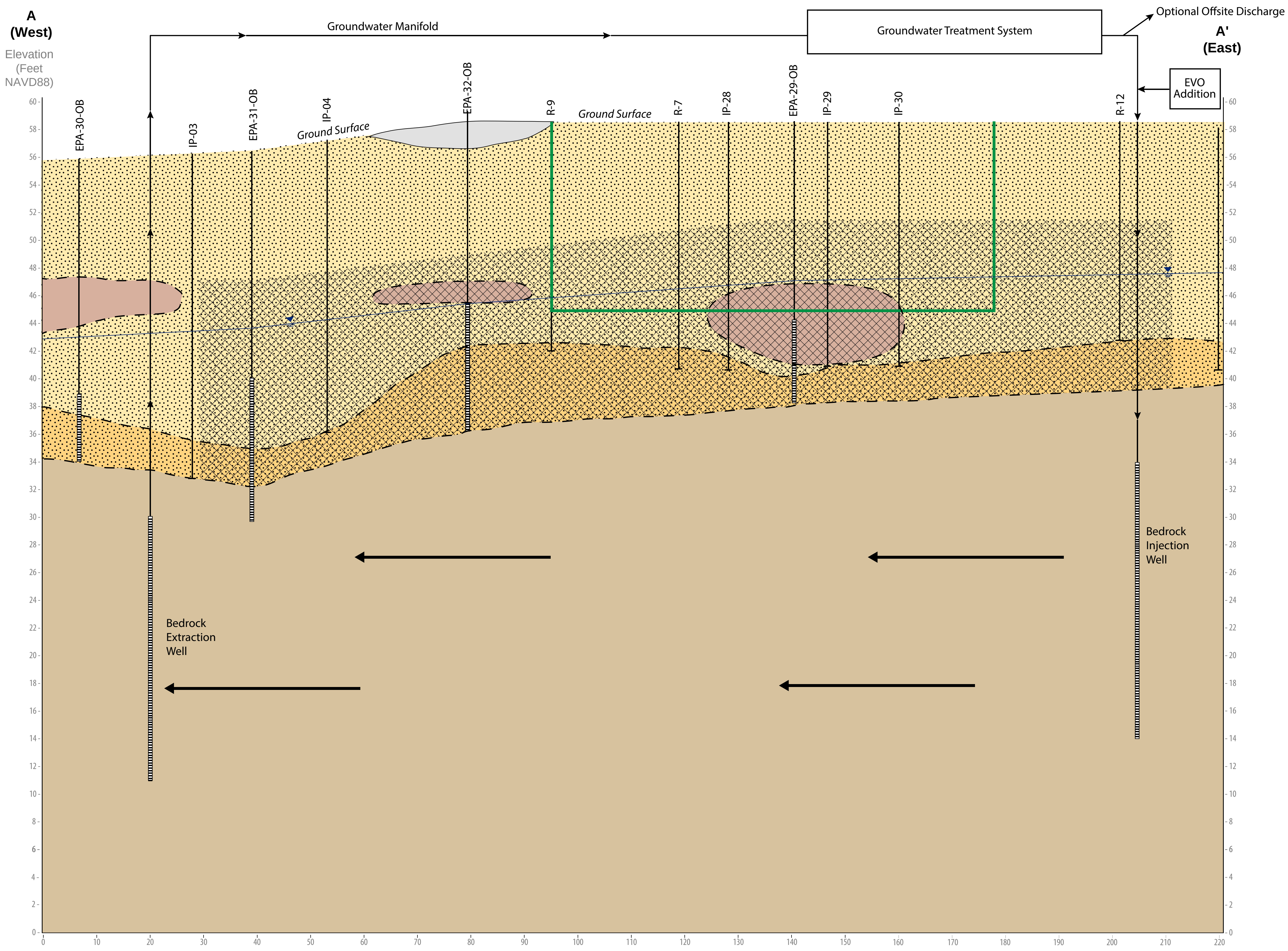

Legend

- Potentiometric Groundwater Surface
- Concrete
- Weathered Sandstone
- Sand with Silt
- Sandstone
- 2014 Excavation Area
- Silt
- Soil Mixing Target Treatment Area
- Dashed Where Inferred

Notes:
Groundwater elevations determined from the average depth to groundwater measurements over the duration of the ECE Pilot Study (June 2014 to March 2015)

2014 Excavation Area filled with coarse grain soil and gravel

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Figure 7-2
Alternative 2A: Source Area Treatment - Soil Mixing, Cross Section View
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Garfield, NJ 07026

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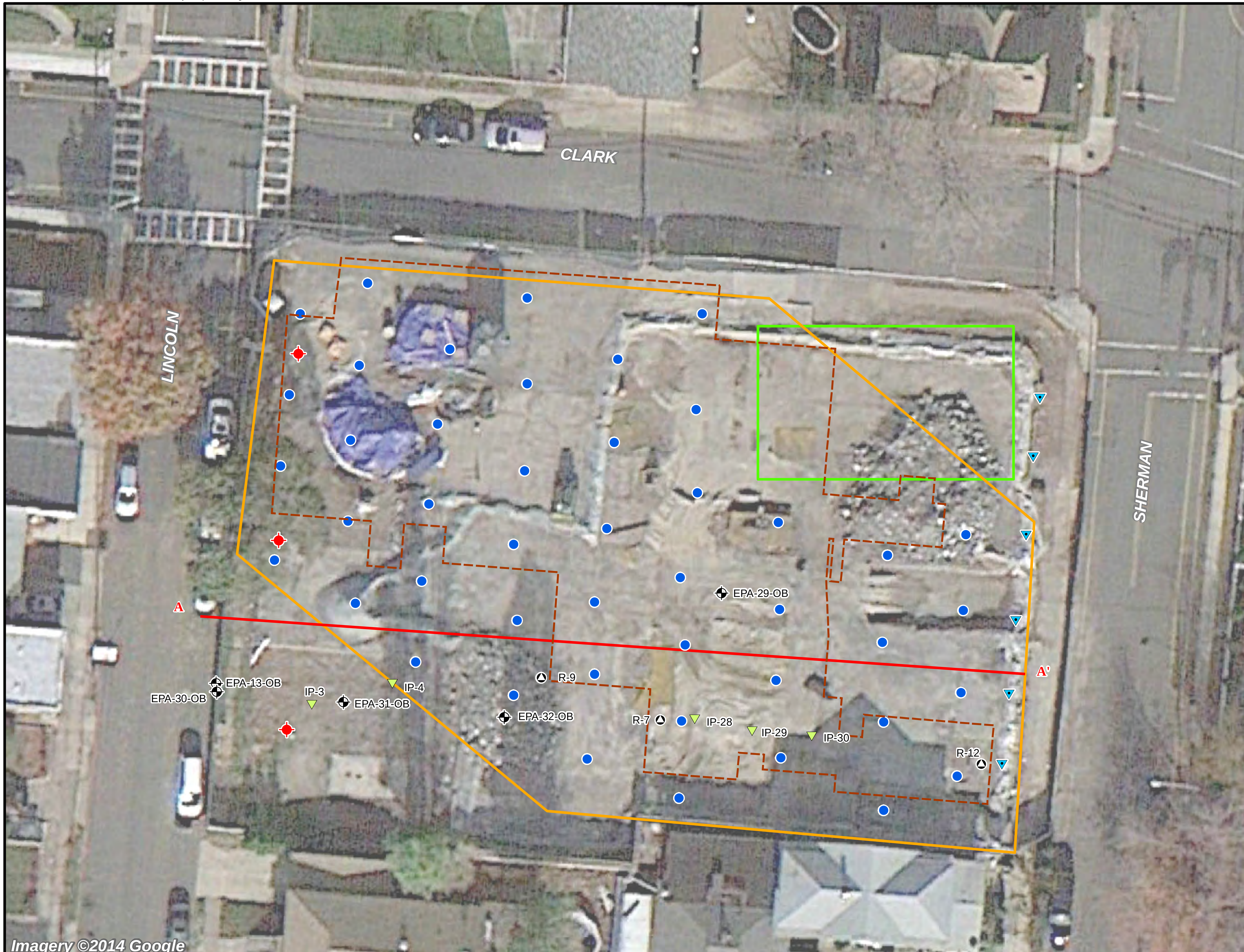

Legend

- In Situ Injection Point
- Monitoring Well Location
- Soil Boring
- Bedrock Injection Well
- Bedrock Extraction Well
- Pilot Study Direct Push Injection Location
- Groundwater Treatment System Building
- In Situ Injection Area
- 2013-2014 Excavation Area
- Cross-section Transect

N

0 12.5 25 50 Feet

NOTES:
New Jersey State Plane Coordinate System, Horizontal Datum NAD83, US Survey Feet
Imagery Source: Google Earth, 2014.

Figure 7-3
Alternative 2B: Source Treatment - In Situ Injection, Plan View
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site, Garfield NJ, 07026

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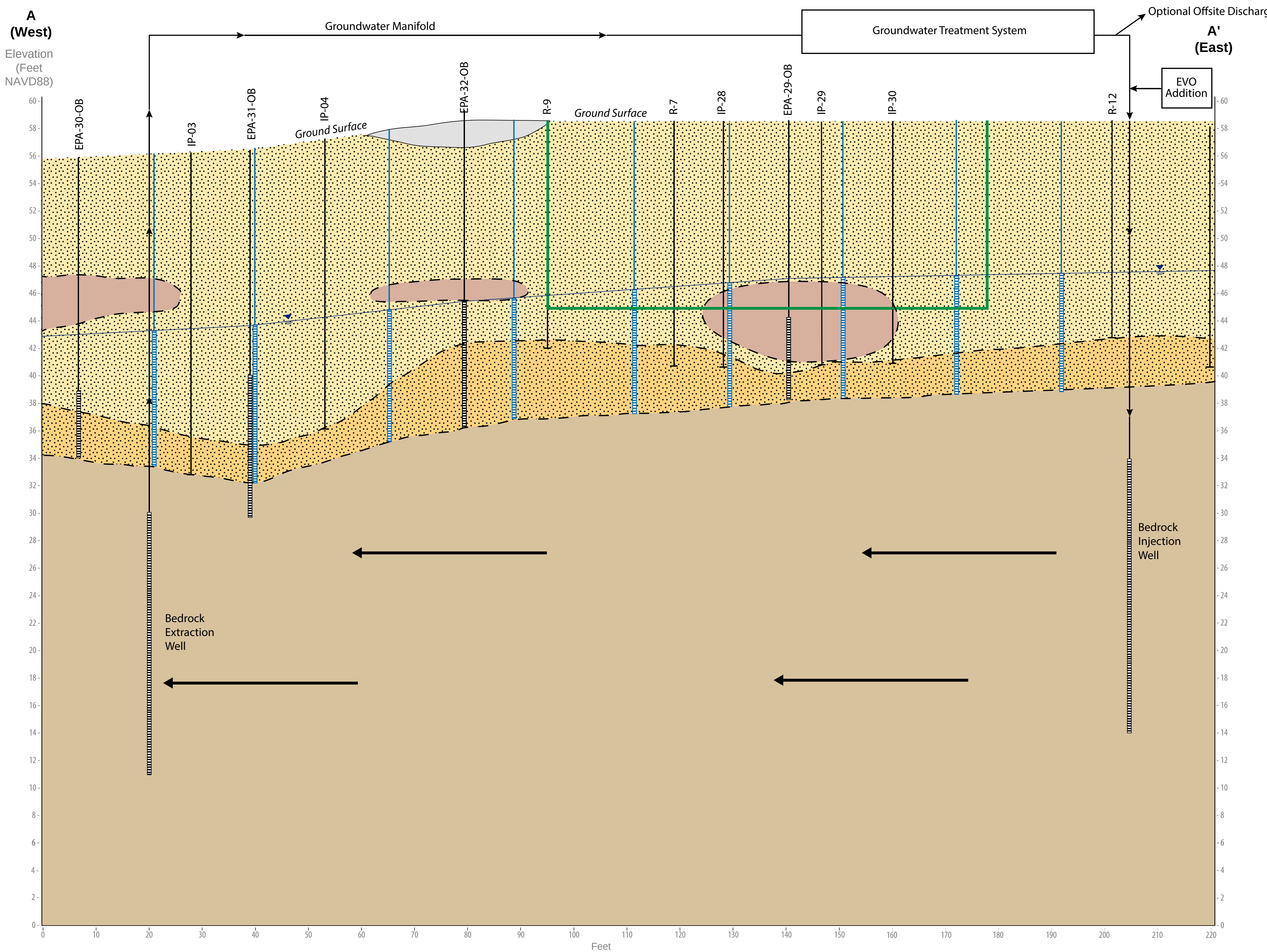

Legend

- Potentiometric Groundwater Surface
- Concrete
- Weathered Sandstone
- Sand with Silt
- Sandstone
- 2014 Excavation Area
- Silt
- Insitu Insection Well
- Dashed Where Inferred

Notes:
Groundwater elevations determined from the average depth to groundwater measurements over the duration of the ECE Pilot Study (June 2014 to March 2015)

2014 Excavation Area filled with coarse grain soil and gravel

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Figure 7-4
Alternative 2B: Source Treatment -
In situ Injection, Cross Section View
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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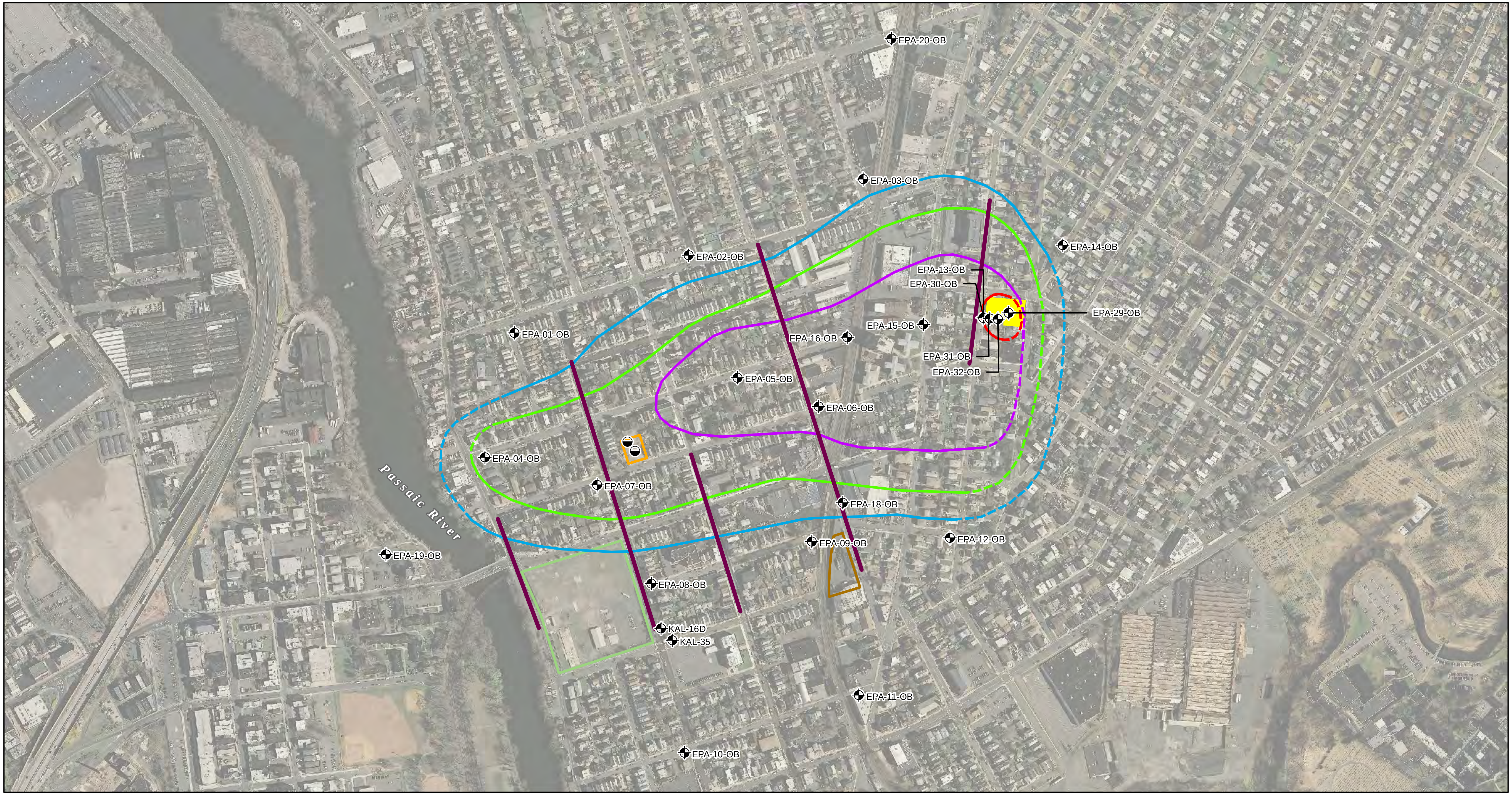

Overburden Monitoring Well
Former Garfield Municipal Well
Grand Street Lot
Kalama Chemical Site
T.A. Farrell Site
Source Treatment Area

Alternative 3 In Situ Reduction Barrier

Approximate Hexavalent Chromium Isoconcentration Contour Lines (Dec 2014)

70 µg/L (dashed where inferred)
700 µg/L (dashed where inferred)
7000 µg/L (dashed where inferred)
70,000 µg/L (dashed where inferred)

NOTES:
New Jersey State Plane Coordinate System Horizontal Datum NAD83, Vertical Datum NAVD88 US Survey Feet.
MSL - Mean Sea Level
Imagery Source: National Aerial Imagery Program, 2010
Screen Interval 1 (Feet Below Ground Surface)
Overburden elevation ranges from 0 to -72.1 ft NAVD88

N

0 250 500 750 1,000 Feet

Figure 7-5
Alternative 3: Source Treatment and In Situ Reduction Barriers for Overburden
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Garfield, NJ 07026

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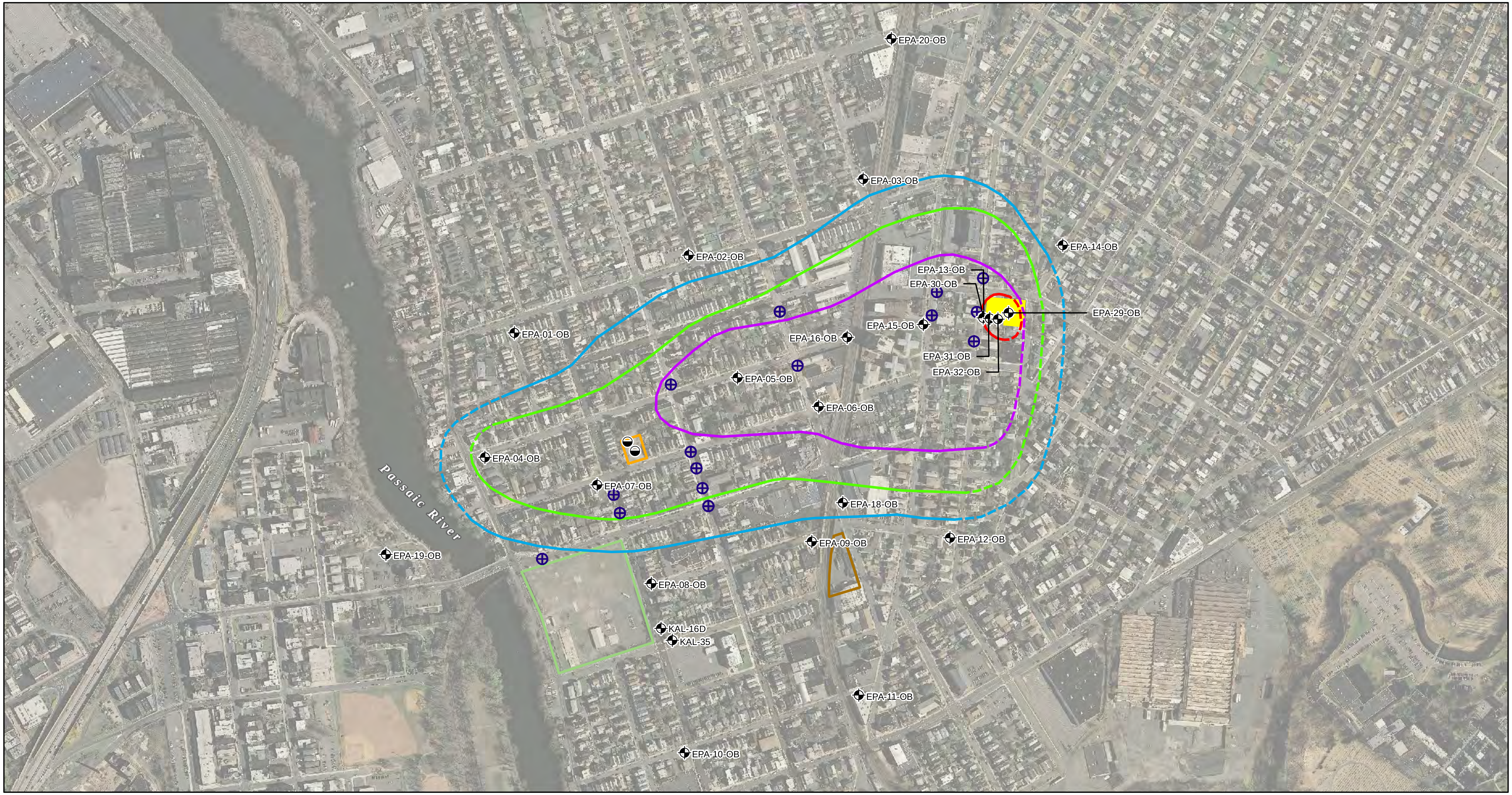

Overburden Monitoring Well

Former Garfield Municipal Well

Grand Street Lot

Kalama Chemical Site

T.A. Farrell Site

Source Treatment Area

Alternative 4 Extraction Well

Approximate Hexavalent Chromium Isoconcentration Contour Lines (Dec 2014)

70 µg/L (dashed where inferred)

700 µg/L (dashed where inferred)

7000 µg/L (dashed where inferred)

70,000 µg/L (dashed where inferred)

NOTES:
New Jersey State Plane Coordinate System Horizontal Datum NAD83, Vertical Datum NAVD88 US Survey Feet.
MSL - Mean Sea Level
Imagery Source: National Aerial Imagery Program, 2010
Screen Interval 1 (Feet Below Ground Surface)
Overburden elevation ranges from 0 to -72.1 ft NAVD88

0 250 500 750 1,000 Feet

N

Figure 7-6
Alternative 4: Source Treatment and Pump and Treat for Overburden
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Garfield, NJ 07026

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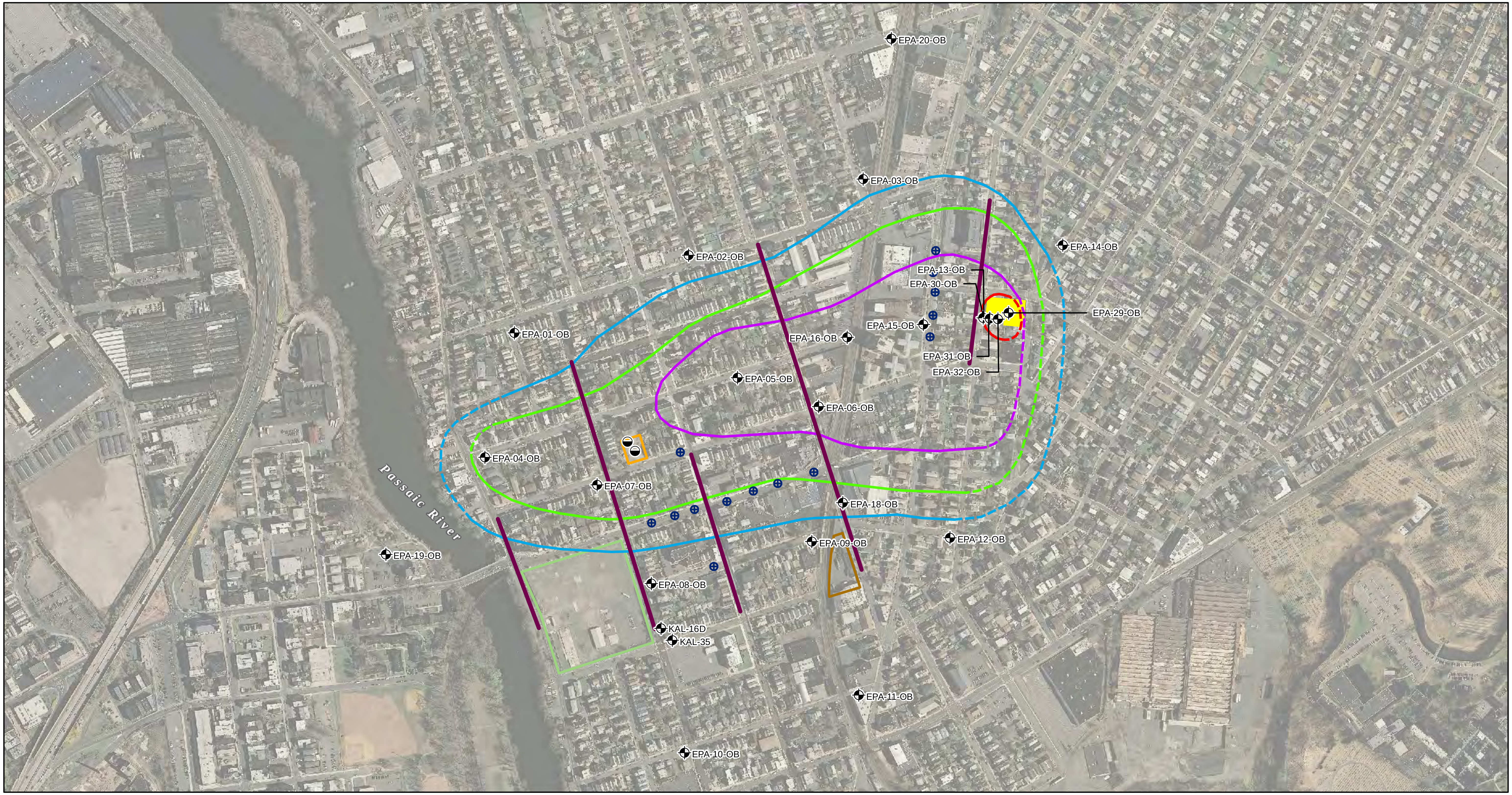

Overburden Monitoring Well
Former Garfield Municipal Well
Grand Street Lot
Kalama Chemical Site
T.A. Farrell Site
Source Treatment Area

Alternative 5 Components
In Situ Reduction Barrier
Extraction Well

Approximate Hexavalent Chromium Isoconcentration Contour Lines (Dec 2014)
70 µg/L (dashed where inferred)
700 µg/L (dashed where inferred)
7000 µg/L (dashed where inferred)
70,000 µg/L (dashed where inferred)

NOTES:
New Jersey State Plane Coordinate System Horizontal Datum NAD83, Vertical Datum NAVD88 US Survey Feet.
MSL - Mean Sea Level
Imagery Source: National Aerial Imagery Program, 2010
Screen Interval 1 (Feet Below Ground Surface)
Overburden elevation ranges from 0 to -72.1 ft NAVD88

N

0 250 500 750 1,000 Feet

Figure 7-7
Alternative 5: Source Treatment and Combined Pump and Treat and In situ Reduction for Overburden
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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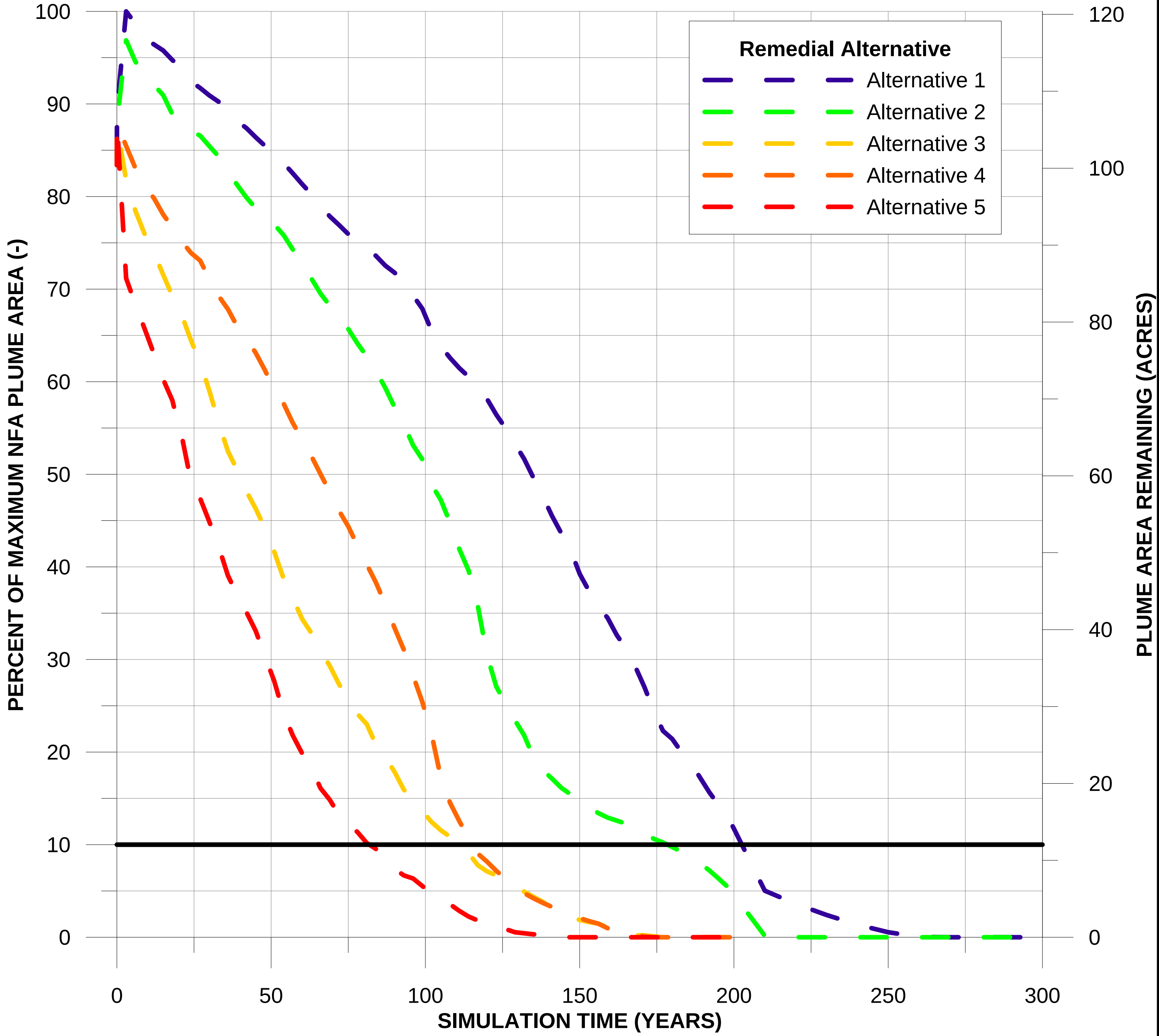

Note:
Plume extent is estimated by the area of all models cells in the overburden (model layer 1) with simulated hexavalent chromium concentrations greater than 70 µg/L.

FIGURE 7-8
Overburden Plume Areas Remaining During Remedial Alternative Simulations
Feasibility Study Report
Garfield Groundwater Contamination Superfund Site
Garfield, NJ 07026

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